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AD-P000 219		Characteristics of Flight Simulator Visual Systems.
AD-P000 220		Filtering Simulated Visual Scenes - Spatial and Temporal Effects.
AD-P000 221		Texture in a Low Cost Visual System.
AD-P000 222		Computer Generated/Synthesized Imagery (CGSI).

FOREWORD FROM THE CONFERENCE CHAIRMAN

The need for effective weapon system training is receiving increased attention throughout the DoD community as the benefits of improved student performance and reductions in training costs are documented. The use of simulation in flight training is now accepted as being highly effective while affording significant reductions in training costs. Similar applications of training and simulation technology are gaining acceptance in such diverse areas as team tactics training, surface and sub-surface ASW, conduct-of-fire systems, and air cushion vehicle operation.

Technological advances in solid state devices, design architectures, software, image generation and display, and performance measurement, to name but a few, are making possible increased training device functionality, effectiveness, reliability, and supportability. The present effectiveness is yielding the long needed documentation of training device payoffs. The recent Defense Science Board study on training illustrates recognition of the growing importance of cost-effective training to this nation's defense.

Recent world events have demonstrated the impact of highly trained military personnel on national defense. World attention in 1982 has been focused on the decisive role training has played at sea, in the air, and on land. These experiences will undoubtedly affect future DoD plans and lend strong support for continuation of the emphasis on training.

Close communication between the military and industry is critical to advancements in training. Without a clear understanding of the military needs and problems in training, effective solutions are doubtful. Conversely, military planners cannot capitalize on the technical and management advances of industry unless they are communicated. The goal of the Interservice/Industry Training Equipment Conference is to serve as a forum to foster this communication. Through technical papers, panels, equipment exhibits, and individual discussions, problems are aired, needs are defined, and plans are specified to develop alternatives and solutions.

The purpose of this conference is communication and the papers contained in these proceedings are an attempt to document both industry's and government's views. These papers were selected to present a wide range of government and industry techniques, issues, problems, and needs.

While past conferences have covered a wide range of training topics, it has become increasingly recognized that the voice of the user must be heard. It is not enough to hear from the acquisition, requirements, design or support specialists. The training equipment user is daily confronted with a diversity of unique difficulties which are frequently unseen by others in the training cycle. Complicating the problem is that few vehicles are available to the user to voice these issues. The Fourth Interservice/Industry Training Equipment Conference is, therefore, focused on the user. Our goal is to communicate the user's views to those in government and industry and hopefully improve the resultant training product.

Dr. James A. Gardner
Conference Chairman

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Members: LT. D.L. Norman, NAVTRAEQUIPCEN

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Headquarters Air Force Systems Command

Doctor Ronald Hofer
Project Manager for Training Devices, U.S. Army

Jon Schreiber
Naval Air Systems Command

Willard D. Haugen
Ogden Air Logistics Center, Air Force Logistics Command

ABSTRACT

The Joint Logistics Commanders (JLC) are composed of the commanders of the US Army Materiel Readiness and Development Command, Air Force Logistics Command, and Air Force Systems Command as well as the Chief of Naval Material. The JLC meet regularly with the Deputy Secretary of Defense. Their purpose is to resolve common concerns and, where possible, to achieve efficiencies by combining efforts. The day-to-day activities of the JLC are carried out by joint panels and groups.

One such group is the Joint Technical Coordinating Group on Simulators and Training Devices (JTCG-STD). Its purpose, as stated in its charter from the JLC, is to identify opportunities to coordinate or consolidate programs in research and development, acquisition, and operation and support of training devices and to implement plans to reduce the cost and/or increase the effectiveness of military simulators and training devices.

That is a large order. To accomplish it requires breaking it into manageable tasks. Each year the JTCG-STD will review proposals for efforts which have high payoffs to two or more services. The best of these will be chosen to be presented to the JLC as candidates for JLC sponsorship. JLC sponsored tasks will be managed by a single command with assistance from the others.

The first three tasks chosen for JLC sponsorship are to develop (1) a standard Defense Mapping Agency data base transformation program, (2) a library of standard electronic warfare threat data bases, and (3) standard training device software acquisition management procedures. The efforts will commence in FY 84 and FY 85. Future initiatives for JLC sponsorship are solicited, and the method for submitting them to the JTCG-STD is outlined.

INTRODUCTION

In the mid-1960s the military services became greatly interested in each others acquisition, supply, and maintenance capabilities. Out of that interest and cooperation grew a structure known today as the Joint Logistics Commanders, or JLC. The early efforts involved such areas as munitions effectiveness and depot maintenance interservicing. Other efforts have been added, and many have been completed. When the 1973 oil embargo caused an upsurge in interest in training simulators, the JLC formed a group to coordinate activities in the realm of training equipment.

The purpose of this paper is to familiarize the training equipment community with the group that has evolved from those early efforts and to solicit ideas on how the services can improve training effectiveness through interservice cooperation. Effective interservice initiatives can benefit the operating commands, the acquisition and support organizations, the training industry, and ultimately, the taxpayers.

THE JOINT LOGISTICS COMMANDERS

The Joint Logistics Commanders (JLC) consist of the commanders of the US Army Materiel Development and Readiness Command, Air Force Systems Command and Air Force Logistics Command and the Chief of Naval Material. USMC liaison is provided by the Headquarters USMC Deputy Chief of Staff for Installations and Logistics. The current members of the JLC are pictured in Figure 1.

While this joint arrangement has no legal authority, other than that delegated to each Commander to accomplish his assigned mission, the JLC management concept has been endorsed by the Chiefs of the Military Departments, the Service Secretaries and the Secretary of Defense. The JLC meet formally at least quarterly and periodically report to the Deputy Secretary of Defense, the Under-Secretary of Defense for Research and Engineering (who is the Defense Acquisition Executive) and the Assistant Secretary of Defense for Manpower, Reserve Affairs and Logistics.

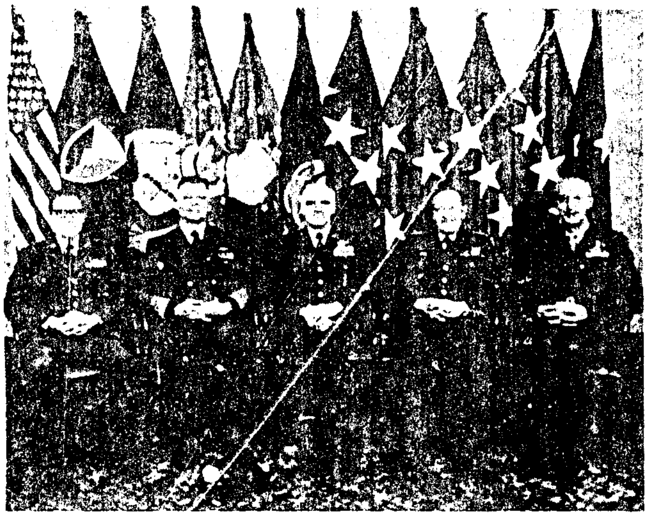

Figure 1. The Joint Logistics Commanders (l to r: Gen Robert T. Marsh, USAF (AFSC); Adm J. G. Williams, Jr., USN (NMC); Gen James P. Mullins, USAF (AFLC); Gen Donald R. Keith, USA (DARCOM); Lt Gen H. A. Hatch, USMC)

Since the JLC are not an official body, there is no JLC staff. Instead, each commander has a member of his special staff who is designated as Assistant for Joint Service Activities. These five are known collectively as the Joint Secretariat, and they carry out day-to-day administrative activities on behalf of the JLC. The JLC themselves meet at least quarterly with each commander taking his turn to host the others.

The efforts which the JLC direct are carried out through various groups and panels. Some of these are created for specific short term tasks and pass out of existence in a matter of months. Others have a continuing mission. Regardless of the duration of the task, each panel or group consists of a principal member from each command, alternate members as required, and an invited USMC participant if the subject is of interest to the Marines. One principal member serves as chairman. The groups and panels report to the JLC through the Joint Secretariat. The group of specific interest to the training community is the Joint Technical Coordinating Group on Simulators and Training Devices (JTCG-STD).

THE JOINT TECHNICAL COORDINATING GROUP ON SIMULATORS AND TRAINING DEVICES

The JTCG-STD was chartered originally in 1976 to minimize duplication in research and development efforts. The problem with that charter was that it did not permit doing something new which would have multi-service payoff. During a five-year-point review of progress, all parties agreed that a potential existed for high payoffs from interservice efforts in the simulator and training device area. The question was how to achieve them.

Several principles were adhered to in laying out the new approach. First, efforts would have to be discrete and measurable, in keeping with the philosophy that the way to eat an elephant is one bite at a time. Second, implementing efforts would have to be done within the framework of existing management systems such as the Planning, Programming, and Budgeting System (PPBS). Third, two or more services would have to share in the benefits. Finally, priority would go to those efforts with the highest return on investment; return being defined as a combination of increased training effectiveness with reduced cost.

Out of these principles grew the concept of "JLC sponsored" tasks. Each year the JTCG-STD will review possible efforts. Those with the greatest payoff will be reviewed by the Joint Secretariat and presented to the JLC. If the JLC agree that the tasks should be pursued, they will adopt them as JLC sponsored. The lead command, with the cooperation of the others, will then enter the task into the PPBS as a high priority new start. Once the system has been operating for several years, each year will see the completion of some tasks, continuation of others, initiation of more, and approval of additional ones.

All of these principles are embodied in the 31 March 1982 JTCG-STD charter which is reproduced in Figure 2. Perhaps the best way to illustrate how the JTCG-STD is operating is to briefly examine three JLC-sponsored tasks initiated by the JTCG-STD.

JLC SPONSORED TASKS

Standard DMA Data Base Transformation Program

Air Force Systems Command is the lead command for this effort, which will be managed by the Deputy for Simulators at Aeronautical Systems Division. It is funded in FY 84 and beyond and the request for proposal will be issued in FY 83. The objective is to reduce the proliferation of transformation programs for Defense Mapping Agency (DMA) digital data. Changes in the DMA specification would be more easily accommodated, and data bases, whether radar, visual, or infrared, would be transportable among training devices. Furthermore, data base enhancements developed for a Navy simulator could be used directly for an Army or Air Force simulator.

Library of Standard Electronic Warfare Threat Data Bases

Naval Material Command is the lead command for this effort, which will be managed by the Naval Training Equipment Center. It will be an FY 85 start with preliminary activities in FY 84. The objective is to be able to produce or update EW threat models once and then distribute the model to all users. Whether this will be done by use of a standard specification or a model library is yet to be determined.

Standard Training Device Software Acquisition Management Procedures

US Army Materiel Development and Readiness Command is the lead command for this effort, which

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CHARTER
FOR
JOINT DARCOM/NMC/AFLC/AFSC COMMANDERS
JOINT TECHNICAL COORDINATING GROUP
ON
SIMULATORS AND TRAINING DEVICES

I. PURPOSE.

A Joint Technical Coordinating Group on Simulators and Training Devices (JTCG-STD) is hereby established. Because the services share the same population base as a source of trainees, the same industrial base as a source of training equipment, and the same potential adversaries as a standard against which training results must be measured, there exist numerous opportunities to coordinate or consolidate programs in research and development, acquisition, and operation and support of training devices. The purpose of the JTCG-STD is to identify such opportunities and to implement plans to reduce the cost and/or increase the effectiveness of military simulators and training devices.

II MISSION.

The mission of the JTCG-STD is to maintain oversight of all activities within the four logistics commands which involve research and development, acquisition, or support of simulators and training devices. Based on this knowledge of planned and on-going activities, the JTCG-STD will identify specific projects for JLC sponsorship which offer high pay-off to two or more services from consolidating efforts into a single, JLC-sponsored initiative. In those instances where JLC sponsorship of a joint initiative is not warranted, the JTCG-STD will insure coordination and exchange of information between and among the services to minimize or eliminate duplication of effort. In addition, the JTCG-STD will facilitate the exchange of information such as technical reports and contractor past performance between and among agencies of the logistics commands to improve the efficiency of operations.

III. GUIDANCE.

The JTCG-STD shall:

A. Be task oriented. As such it will identify and sponsor discrete tasks with high pay-off to two or more services. These tasks, or initiatives, will be of finite duration with measurable goals.

B. Communicate with appropriate groups and panels of the Interservice Training Review Organization (ITRO) to reduce or eliminate duplication of effort.

C. Coordinate with the Directorate of Research and Technology, Office of the Under Secretary of Defense, Research and Engineering to eliminate duplication between the JTCG and the Simulator Technical Advisory Group (SIMTAG).

D. Communicate with other major commands such as TRADOC, ATC, and CNET which are also involved in training device acquisition to maximize the benefits of interservice cooperation.

Figure 2. JTCG-STD Charter

E. Encourage the use of the annual Interservice/Industry Training Equipment Conference as a primary vehicle for the interservice exchange of information among members of the military training device community.

F. Establish formal means of communication between the JTCG and service peculiar simulator and training device coordinating organizations such as the USAF Simulator Advisory Group (SAG).

IV. REQUIREMENTS.

A. Annually, in time to influence preparation of the service Program Objective Memoranda, the JTCG-STD shall identify to the Joint Secretariat new joint service initiatives for JLC sponsorship. Initiatives shall be documented in the format of Appendix II to the Handbook for Joint Logistics Commanders Panels/Groups.

B. Annually, on-going JTCG-STD sponsored initiatives shall be reviewed to determine whether continued JLC sponsorship is warranted. If not the JTCG-STD shall recommend to the Joint Secretariat that JLC sponsorship should be withdrawn.

V. ADMINISTRATION.

A. Periodic reports will be submitted in accordance with the Handbook for Joint Logistics Commanders Panels/Groups.

B. Funding for a JTCG-STD sponsored initiative will be programmed and budgeted by the lead logistics command for that initiative. Support of the initiative by the other logistics commands will be from existing resources.

C. JTCG-STD initiatives approved by the JLC will be supported by the logistics commands to the extent necessary to assure that the benefits of interservice cooperation will be realized.

D. Lead command responsibility for JTCG-STD initiatives will be equitably distributed provided sufficient expertise exists within a command to effectively lead the effort.

E. Subgroups may be established from time to time with the specific approval of the OPRs in accordance with the Handbook for Joint Logistics Commanders Panels/Groups.

F. In order to identify areas for coordination or consolidation of efforts, the JTCG-STD may review planned and on-going simulator and training device programs at meetings of the JTCG.

G. Adequate resources including travel funds will be allocated to JTCG-STD activities to permit timely and effective operations.

Donald R. Keith

DONALD R. KEITH
General, USA
Commanding
U.S. Army Materiel Development
and Readiness Command

J. G. Williams, Jr.

J. G. WILLIAMS, JR.
Admiral, USN
Chief of Naval Material
Naval Material Command

James P. Mullins

JAMES P. MULLINS
General, USAF
Commander
Air Force Logistics Command

Robert T. Marsh

ROBERT T. MARSH
General, USAF
Commander
Air Force Systems Command

DATE: 31 March 1982

Figure 2. Continued

JTCG-STD INITIATIVE FOR A STANDARD DMA DATA BASE TRANSFORMATION PROGRAM

PROBLEM

A new, unique transformation program has been procured for every simulator and training device whose radar or visual system uses Defense Mapping Agency (DMA) data. Worse, when DMA changes the specification to which it digitizes world-wide data, each previously procured transformation program must be revised to accept DMA data which meets the new specification.

BACKGROUND

The Defense Mapping Agency integrates a variety of data sources to produce a digitized data base. This data base is used in training devices to present the outside-the-cockpit scene to the aircrew as visual, ground-mapping radar, infra-red, or other sensor information. However, the ones and zeroes which compose the digitized data base cannot be presented directly; they must be manipulated to return them to a real world form. A data base transformation program performs this function.

Any data base which DMA produces is formatted and detailed according to the specification in effect at the time of production. Any change in that specification requires changes in the transformation programs which will be used to process the data base. The specification has been changed every three or four years on the average.

DISCUSSION

There are no theoretical reasons why DOD could not maintain a single data base transformation program. The government could then provide the program to training device manufacturers as GFE and could revise it concurrently with data base specification changes. Thus, the services would no longer be paying for multiple programs and multiple updates. Furthermore, some of the products themselves (for example, enhancements to the DMA data base) would then be transportable between training devices.

In practice, the number of data base transformation programs required might be two or three, depending on application (radar, visual, infra-red) or device sophistication (part task trainer, full mission trainer). However, even a reduction to two or three data base transformation programs would result in substantial savings to DOD.

CONCLUSION

An effort to develop a standard DMA data base transformation program is required.

ORIGINATOR

Name, complete mailing address, phone number (AUTOVON for DOD personnel).

Figure 3. Abstract format

will be managed by the Project Manager for Training Devices. It will begin as soon as planning can be completed since it will be done primarily within the government. The objective is to reduce costs to us by allowing a contractor to apply the same software management procedures, reviews, and data items to all the Defense Department training device contracts in his plant. The team which undertakes this task will coordinate its work with the JLC's Joint Policy Coordinating Group on Computer Resources Management (JPCG-CRM). Training device software and computers are exempt from the requirements applied to embedded computer resources, but the JPCG-CRM work is a useful starting point for training device efforts. Needless to say, the JTCG-STD will work with industry on this task.

CHALLENGE TO THE TRAINING COMMUNITY

Those three JLC sponsored tasks illustrate the broad features of the sort of efforts the JTCG-STD is chartered to undertake. But the JTCG-STD has no monopoly on ideas. The JTCG-STD needs your help. If you have an idea to solve a problem and it meets the general criteria outlined in this paper, the JTCG-STD wants to know about it.

The initial review requires only a one page abstract in the format of Figure 3. Based on the abstract, the JTCG-STD will return it because it does not meet the criteria, hold it for future sponsorship, ask for additional information, or recommend it for JLC sponsorship.

Send your abstract to the appropriate address listed below.

If you are Army:

US Army Project Manager for Training Devices
DRCPM-IND-E
Attn: Dr. R Hofer
Orlando, FL 32813

If you are Air Force:

Ogden Air Logistics Center
OO-ALC/MMF
Attn: Mr. W. Haugen
Hill AFB, UT 84406

If you are Navy, USMC, or Defense Agency:

Commander, Naval Air Systems Command
NAIR-4131
Attn: Mr. J. Schreiber
Washington, DC 20360

If you are outside the Department of Defense:

Headquarters Air Force Systems Command
HQ AFSC/SDTA
Attn: Lt Col G. Winters
Andrews AFB, DC 20334

CONCLUSION

As the military services view the world of training, many things look the same--because they are the same. We share the same threats. We share the same pool of potential trainees. We share the same training device industrial base. We share the need to provide effective training at an optimum cost. As a result, the services could do much together.

The Joint Logistics Commanders have accepted the challenge to do more together in the training device area and have chartered a Joint Technical Coordinating Group on Simulators and Training Devices to make it happen. In turn, the JTCG-STD needs the help of the training community. Together we can achieve the goals the JLC have established. The services, the industry, and the nation will be the beneficiaries.

ABOUT THE AUTHORS

LIEUTENANT COLONEL GEORGE R. WINTERS is Air Force Systems Command (AFSC) principal member of the JTCG-STD and serves as its chairman. He is Chief of the Avionics and Training Systems Division in the DCS/Systems at Headquarters AFSC. His previous assignment was as program manager of the Tactical Combat Trainer Program (Project 2360) at the Deputy for Simulators, Aeronautical Systems Division. He received a Bachelor of Metallurgical Engineering degree from Cornell University and a Master of Science in Aerospace Engineering degree from the U.S. Air Force Institute of Technology. He is a graduate of the Program Management Course of the Defense Systems Management College and is a registered Professional Engineer.

DOCTOR RONALD HOFER is the US Army Materiel Development and Readiness Command principal member of the JTCG-STD and is a past chairman. He is Chief Engineer for the Army Project Manager for Training Devices and Chief of the Operations Research and Engineering Management Division. His previous assignments have included program management and laboratory efforts at Fort Monmouth. He received BSEE, MSEE, and Ph.D. degrees from Purdue University.

JON SCHREIBER is the Naval Material Command principal member of the JTCG-STD. He is Head of the Attack Training Branch in the Weapons Training Division of Naval Air Systems Command. He received a Bachelor of Engineering degree from Youngstown State University and a Master of Engineering Administration degree from George Washington University. He was honored by the Navy with a fellowship as legislative assistant to Senator Jeremiah Denton of Alabama.

WILLARD D. HAUGEN is the Air Force Logistics Command principal member of the JTCG-STD. He is Chief of the Systems Management Section in the Training Devices System Management Division, Ogden Air Logistics Center. He has completed numerous courses at Weber State College.

GETTING USER REQUIREMENTS INTO THE DEVELOPMENT-TO-DELIVERY LOOP

Frederic W. Snyder
Boeing Military Airplane Company
Wichita, Kansas

ABSTRACT

Many who coordinate with military users of training systems are aware that some trainers fail to satisfy important user requirements. Conscientious people working in the requirement-to-delivery loop may never intentionally neglect or distort end-user needs. However, such oversight or misunderstanding does occur within the operations of complex military, government, and industry organizations. The character of formal and informal information flows within and between these organizations as they relate to identification, establishment and communication of requirements hold the key to improved procedures. What is recommended is consideration for increased emphasis on the collection and use of unfiltered needs statements of lower echelon users during the system development-to-delivery process. This envisioned emphasis would also include information feed-back loops to the end-user culminating in a user orientation manual covering the intended purpose of the trainer, a brief history of the system development, and training, logistics support, and maintenance philosophies.

INTRODUCTION

It is a vital concern of the using organization and the military training system contractor to know about and understand the problems user personnel are having with a current trainer. Unresolved or partially solved problems of this sort lead to requirements for system changes or, in time, to replacement systems. As an alternative, a service-oriented contractor may suggest or participate in a reorientation of the approach to trainer use, maintenance, and logistics support that will enhance the value or extend the useful life of the system in close coordination with user personnel.

Where the system is in current operation and unresolved problems lead to modified or new systems, we can easily see the validity for strong inputs to requirements by lower echelon users. However, when a new mission requirement dictates a fairly radical change in the functional requirement (e.g., advent of the weapon system trainer), or when the state-of-the-art enables the start of a new generation of training systems (e.g., the computer image generation visual system), or when cost-effectiveness of training systems becomes the major issue, then the origin of the requirement comes from a different part of the governmental or military organization and it is not so easy to determine how the ultimate user should be involved in the establishment of needs, requirements, and specifications as well as in other phases of development and evaluations. For the potential user and all others concerned, there is less information directly based on experience and more emphasis on trying to bridge between the known and the unknown. This gap becomes wider the more radical the change from current to future system concepts.

The thesis of this paper is that the ultimate user (instructor cadre, maintenance personnel, logistics personnel) should participate in establishing and evaluating system needs, requirements, specifications, development, test, and evaluation for all trainers. This participation may at times be formal or informal. It may consist of orginating or reviewing paper work, coordination, telecons, going to and participating in meetings and reviews, participating in tests and evaluations, receiving orientation briefings trainings on and evaluating new system concepts, being interviewed or answering questionnaires, participating as a panel of user experts to support contractor design efforts, or participating as trainer operators, maintainers, or logistic support persons in research and development tests.

It is realized that there are many factors and constraints working against the user's systematic involvement, one of the most important being allocating the time away from work and the costs of travel and subsistence. Other important factors are the constraints imposed in competitive bidding and competitive fly offs, and strong attitudes of independence by representatives of some companies and government agencies. If greater involvement and input by the lower echelon user in the requirement-to-delivery process is viewed as a priority, then these and other constraints will be viewed as a challenge and a way often will be found to facilitate such participation. One of the most critical phases in new system concept formation and development needing inputs from the user is during the preparation of the needs statement and in the process of requirement definition and authentication. First we need to define what we mean by "requirement."

DEFINING "REQUIREMENT"

"What is a requirement" may be said to have a double meaning in the systems development-procurement cycle. First, it means defining the authentic requirement which, in one form or another, can be used to blaze the trail toward adequate fulfillment of a user's need. Second it means that the whole process starts with a careful definition of "WHAT." "WHAT" (i.e., what is really required) is the only question that should be allowed at this stage. Considering other questions too soon only confuses the requirement issue. For example, when the question "HOW" is brought up too soon, the requirement development and communication process becomes confused because everyone tries to solve a problem that hasn't been properly defined. The strongest urge seems to be to hurry through the problem definition in order to get on with the solution, only to find after months or years of development and even production, that the solution does not fit the real-world problem. Perhaps this is so because many more people and organizations of people appear better equipped to solve problems than to ask questions and systematically and correctly define problems.

Sometimes these two different groups oppose one another when they should cooperate to better define and fulfill a requirement. Typical arguments used on one side are "Stop wasting effort on an ill-defined problem," or on the other, "We're wasting too much effort on understanding and defining, let's get on with a solution." Some argue for a middle ground which places both sides in competition with checks and balances, but that tends to stretch things out. Soon the schedule is tight, the budget is short, and there is no room for redefinition of a problem, only battering attempts to try to solve whatever seems to be the requirement.

What is recommended is that the important term "requirement" be defined and communicated. The requirement analysis should not be contaminated with design solutions even if those who are establishing the "HOWs" start to work to establish feasible system solutions during the same time as those who are still trying to establish "WHATs" (or requirements). This is the ideal time to utilize inputs from lower echelon users who presumably are not design engineers or requirements specialists and should be encouraged to think in terms of requirements and alternative broad functions that need to be accomplished to fulfill the requirements.

THE AGENCY REQUIREMENT

In order to view the full potential of opportunities to get user requirements into the trainer development-to-delivery cycle, we next look at the process by which the agency requirement is orginated, coordinated and fulfilled by development of a new system.

Government policies, regulations and procedures tend to create a check and balance approach and deliberately involve all affected parties to establish and authenticate adequate requirements, which when fulfilled, will satisfy the assigned mission(s) of the agency. Forms have to be filled out, signed, and transmitted through the proper channels. Suggestions for improvement are studied which may die or be revised and transmitted to another format, perhaps as a statement of need. Many are tabled. Surviving requirements are funded for further study, preliminary development and specification writing. If additional funding is authorized and if industry is to participate, a request for proposal is prepared.

Typically, while all of the official actions described in the policies, regulations, and procedures are taking place, many unofficial actions are occuring. The birth of a firm requirement often takes a lot of time. Anyone who has carried the banner for a new requirement knows how difficult it is to find success. Banner carriers are essential and may encounter strong attitudes and feelings, such as the status quo – "Don't rock the boat" and "Let's make do with what we have." There are memos, phone calls, and trips. But establishing a firm requirement for an important mission is worth the effort.

Not all of the developmental effort is expended within the governmental agencies. If the requirement is expected to result in a contracted, funded development program, industry begins parallel efforts to try to understand and even participate in the establishment of the requirement. Studies are performed using research and development (R&D), bid and proposal funds, or under contract to the agency. Frequent contacts are made with user, requirement, R&D, procurement and finance personnel in the agency or support organization.

Now this sounds like a good way to establish useful requirements and it works well when there are skillful coordinators and communicators and "banner carriers" dedicated to understanding, defining and fulfilling basic user needs. An example of what can happen is that an influential person or group can favor a certain kind of new system. The system technology is on the cutting edge of the state-of-the-art, and still under development. It does not yet meet the user required specification and degrades training capability. Nevertheless it is the favored solution. The users may not have sufficient authority to demand the system that best fits their needs. In specific instances there may be justifiable reasons for overriding user requirements just as there may be justifiable reasons why some users persist in demanding that their training equipment requirements be met. What is suggested here is that there be a fair and hopefully somewhat impartial arbiter of honest differences. The procurement system already has the checks and balances intended to resolve such problems.

COMMUNICATING AND THE INDUSTRY ROLE

The simplified communication process of a requirement as it is done within the needing agency may look something like what is shown in Figure 1. The details including iterations will vary depending on such things as procedures, where the need orginates, the priorities, the complexity, cost and length of the program required to fulfill the needs, and how much opposition is experienced.

Industry representatives are sometimes allowed to participate in this process. They are used as consultants. They do studies. They provide information for agency presentations. They help make presentations to establish firm requirements. They travel and they convey messages.

The way the agency has of communicating within is by internal instruments, such as the Justification of Major System New Starts (JMSNS) submitted with the Program Objectives Memorandum (POM). A budget line approved by Congress and a Program Management Directive (PMD) are confirmation of a firm requirement as well as providing the means of meeting the requirement. Certain aspects of these internal messages are made known to industry through briefings or other means. The official message of a beginning procurement process is usually made in the "Commerce Business Daily," but if that is the first time a company learns of the requirement, it is usually too late for them to respond effectively.

The notice in the "Commerce Business Daily" is valuable and for legal reasons essential in the procurement process. However, industry specialists who have been working on a pre-proposal effort for months have been known to read a notice so veiled that they did not recognize the item as related to their effort. What is recommended is a more specific and revealing notice pre-evaluated for language clarity and simplicity.

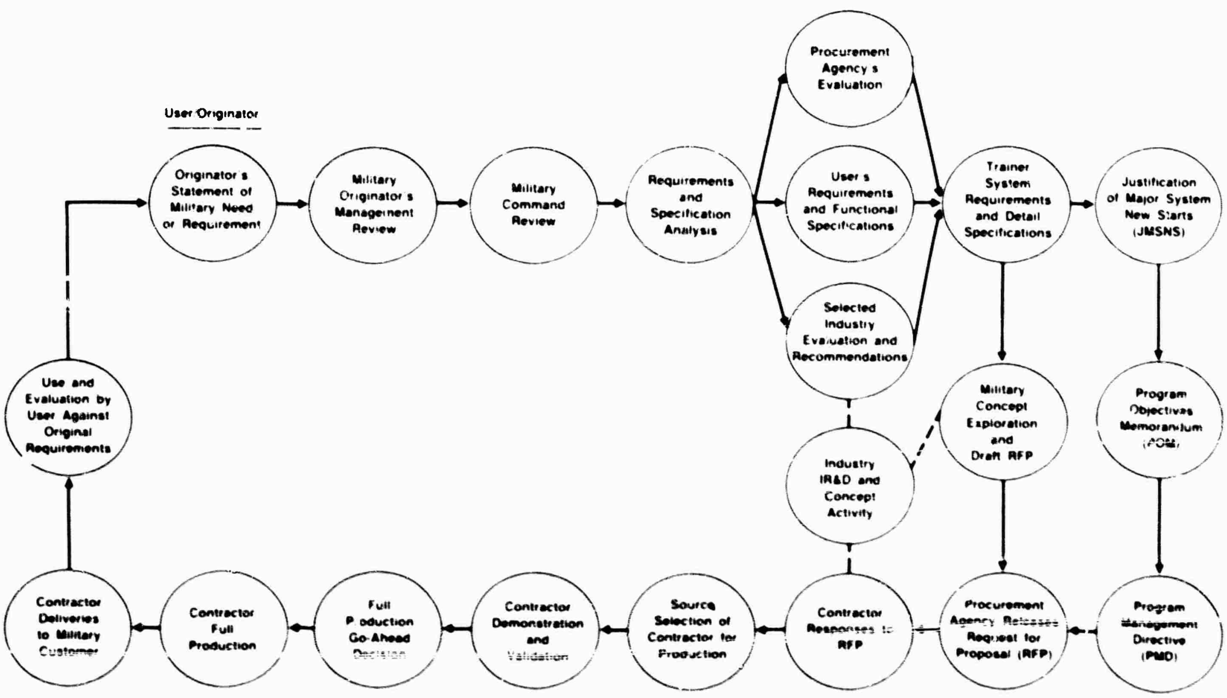

Figure 1. Communication of a Requirement (Typical)

The value of user and procuring agencies and selected industry representatives interacting during requirements definition and development are obvious. The most obvious is the expertise that can be brought to bear on development of viable requirement pros and cons from an independent source. Although one school of requirement definition says requirements should be defined apart from the effort of obtaining solutions, there is almost always a vigorous interaction between requirements and the means of meeting those requirements. For example, among the first thoughts a manager has regarding a proposed requirement is how much will it cost? How long will it take? This means feasible solutions as an integral part of a requirements definition and authentication are looked at very early. Ordinarily, industry is regarded as the prime inventors and doers of the solutions intended to meet such requirements. Industry has preliminary design capabilities, including requirement analysts who are knowledgeable and can be tasked to work closely with the agency in defining, developing and selling a significant requirement. But just because a liaison has been established does not mean that all is well in the communication process.

Traditionally the tendency is for coordination to occur between industry and agency personnel at similar echelon levels. Although Figure 2 undoubtedly oversimplifies the fact, it makes a point. Figure 2a shows that in industry and military agencies, the presidents and vice presidents tend to talk with the generals, the chief engineer talks with the colonels, the project engineer tends to talk with the majors and captains and the engineers talk with the lieutenants and sergeants, etc. The industry marketing man or the program manager usually has more flexibility but tends to talk with higher level management. The specific levels involved are usually determined by the size and importance of the program or potential program that affects the rank of the management position established to head up the project. Something could be missed unless all levels are at least aware of all data in the requirements.

Although perhaps somewhat exaggerated, Figure 2b shows the recommended approach to establish and maintain system requirements and development communications. Informal communication works this way if the freedom is allowed at least to some extent. Although there are many who would feel that the requirement for discipline and order in an organization would be compromised by such activity, those who have risked experimentation of this method, even to a limited extent, see merit in this approach. Whether official communication of this sort is to be allowed depends on the people and the operating procedures in the organization. There are places in both military and industrial organizations where it has been observed working well, at least in an informal mode.

CRITIQUING THE REQUIREMENT

An agency procedure for defining and authenticating firm requirements should, and often does, take into account that differing and even competing points of view should be considered, studied, discussed, and hard decisions made. Basic technical requirements are tempered by such practical matters as priorities, availability of money, manpower and facilities, opinions of authorities, and competition. All requirements go through a process of critique and modification before finalization.

For example, for many years there has been a technical requirement for motion in flight simulators for certain mission segments such as takeoff and landing, but only in recent years has the effectiveness part of the cost-effectiveness formula taken precedence. Because of the cost consciousness aspect of procurement in a highly inflationary period, even the definition of the "cost-effective procurement" seems to have changed. The original idea was to achieve some kind of balance between the cost of a system and the effectiveness produced by the system. Some consider the cost all that really matters but I don't believe it. In my home we have a rule —don't buy the cheapest product if no one will use it. Perhaps part of the problem is that the buyer and user are not in the same "household." The buyer may not know if what he buys is ineffective or even unusable and he may never find out because on programs with long developments, many times the originators and "players" transfer to other jobs before the end item is delivered.

Experience indicates that no statement of need, no required operational capability, no functional or even detailed specification is ever absolutely complete. This frailty in communication is usually not discovered until rather late in the game, perhaps during hardware-software integration or system test and evaluation, or sometimes not until operational testing and eventual use. Those sensitive to this problem should allow for this. The recommendation is that after doing all we can to communicate our requirements and specifications adequately, we build in feedback systems to check out the responses of the receiver to the senders message and see if the

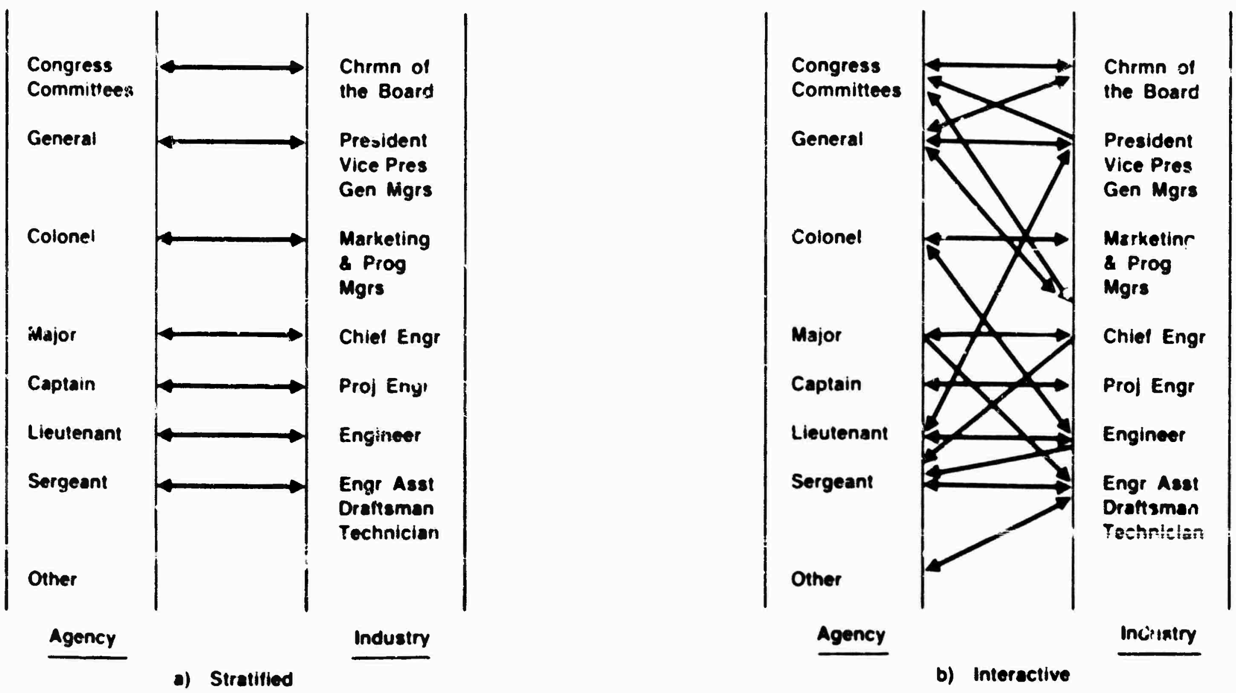

Figure 2. Agency - Industry Communication Modes (Conceptual)

receiver understands the message. This involves far more than merely asking the receiver "Do you understand?" and hearing his response, "Yes."

AVENUES FOR IMPROVEMENT

Let's next explore an analogy, a training system development approach, and topics on assuring trainer fidelity and usability that focus attention on the process of defining and getting user requirements into the development-to-delivery loop. It's not that we understand precisely what goes on and that we can put our finger on a solution. We just know that this "loop" is a very complex problem formulation and communication process usually involving many people over a period of time.

1. The "Open Shop" Approach

The difference between the "closed shop" and the "open shop" as it relates to a customer getting what he's ordered may help to further define the problem and suggest another avenue for solution. In the "closed shop" procedure, you write up your order as best you know how and slip it in the slot on the shop door that says "incoming orders." Then you wait and what you thought you ordered is delivered through a chute marked "orders delivered here." It may or may not be what you expected but you are obliged to use it the best you can. Sometime later you are allowed to make changes or even to try all over again.

In the "open shop" you can enter and talk with someone inside until you both are confident on an agreement of requirements and expected product capabilities to meet those requirements. In the "open shop" you are free to participate and can even influence the development of the product. The product will still be the result of compromises, and will not do everything you would like, but by means of personal representation your highest priority requirements are usually met in a cost-effective and timely way and you certainly are not surprised by what you get upon delivery. The "open shop" approach assures that the original messages of ultimate user needs are not garbled, twisted or lost. If the message does not appear clear, seems exaggerated or even unrealistic, a discussion is arranged with the originator. Once we have a clearly written originator needs statement, it should be carried along with all endorsements or rebuttal statements of superiors, consultants, engineers, requirements people, procurement specialists, finance specialists, or anyone who would propose approval, disapproval, or changes to the original statement. All would include reasons or proof of their statements as applicable. All who see the requirement in succession would see the whole file of communications. At important decision junctures in authenticating a requirement, coordination with as many of the participants in the process as appropriate and practicable would be carried out, especially with the originator. This type of coordination would not preclude systematic studies of related needs throughout the agency involved which might be satisfied with a single development and procurement program.

2. Adapting the ISD Approach

The Instructional System Development (ISD) process is an attempt to establish grass roots training requirements in a systematic manner, relying more on a detailed analysis of the task to be trained rather than on the opinions of expert trainers and their trainees. Perhaps not all tasks require a detailed analysis if carefully planned and systematically obtained expert opinion can determine what the critical tasks are in training and emphasize detailed analysis only of these. Expert opinion on all aspects of training requirements should be obtained and compared with analytically derived requirements in the ISD process with care taken not to influence the one with the other too early in the requirement definition process.

It should be recognized that "grass roots" includes the working level as well as lower echelon management. In establishing flight training requirements, for example, we need written and oral statements from the flight line and training simulator instructors and their trainees. These statements can often be obtained in well planned interviews and discussions and through questionnaires which include open-ended questions. Getting upward-filtered grass roots opinions is an essential part of the requirement definition process but should never be permitted to supplant investigation at the subordinate levels.

3. Assuring Fidelity

An observation made earlier in this paper concerned the difficulty in including in the writing all of the details in the requirements and specifictions necessary to assure a usable trainer. An outstanding example is the present inability to fully specify airplane handling qualities requirements for flight trainers. The contractor understands this problem and plans a period for "tuning" the system after the system has been qualified using all available specifications and applicable airplane source data as a guide. In our experience, qualified pilots are seldom completely satisfied with the flight simulator handling qualities on the "first flight" even though the system may have passed all other system specification tests. And when the customer test pilot flies the flight simulator he sometimes does not like how it handles. At this point, a period of time will be required to fine tune the system to a baseline acceptable to the customer pilot.

What should be recognized is (1) the inability to fully specify handling qualities is a current state-of-the-art limitation, and (2) until overcome, it is recommended that this limitation be recognized in the acceptance test procedure, the schedule, and the program budget.

4. Assuring Trainer Usability to Train

The present difficulty in fully specifying the use to which a system will be put is perplexing and persists to some extent even when ISD procedures have been in effect. Given serious voids, the contractor may (1) guess, (2) ask a lot of questions of the customer procurement personnel, which he is reluctant to do for a variety of reasons, (3) conduct company (usually abbreviated) training requirements analysis and display the results to the customer for comment and possible dialogue on this important subject, (4) visit and talk with customer user personnel and ISD specialists about their training requirements (but they may not fully understand in terms of a new-concept trainer), (5) hire highly qualified former customer user personnel (if possible) to advise contractor management and engineers in their preliminary design proposal and full-scale development effort, or (6) use a combination of these and other approaches.

Because training effectiveness is an elusive factor, it is recommended that agency and industry work harder trying to specify, understand, and comply with the specifications. Until the state-of-the-art allows for more adequate specifications, perhaps an acceptance "tuning" procedure agreed to by both the procuring agency and the contractor is needed that can be used to establish more exactly what the user needs in interaction with the actual training device. Obviously some flexibility in the systems, such as in the instructional system, will be required to enable "tuning" to the needs of the instructor pilot. It is further recommended that consideration also be given on selected programs to have a user representative or panel on site of the contractor during both development and test evaluation.

ALTERNATIVE

Communicating is a difficult art and can be very frustrating. Care must be taken that frustrations do not take on a personal nature, when a new look at the whole process is more in order. Take a situation where a customer knows in his own mind what he wanted his new system to do and had high expectations only to discover far less capability than he expected during acceptance tests. Or imagine the frustration of conscientious company people who really want to satisfy a customer but cannot seem to even though the system meets formal specification requirements The usual trade-off is either a dissatisfied customer who in time finds some way to use the new trainer, or a series of engineering changes to improve the system if the customer can afford them

To alleviate the frustration, we need to come to grips with certain basic problems:

1) Recognize the need for improving the requirement-specification communication process

2) Define and establish an approach to accomplish the needed improvements

3) Where necessary, accept current limitations in statements of requirements and specifications and build in feed-back loops to close the communication information gap

4) Correctly assess the source of apparent human and organization limits to communicate requirements and specifications and assign alternative methods in both planning and development to overcome communication weaknesses

5) As part of the user maintenance manuals prepare a final feedback on the whole development process that summarizes the contractor's interpretation of contract specifications, how they were met, and operating guides for the user to use to attain the performance intended by the original requirements Perhaps the manuals could even precede delivery of the trainer equipment so surprises would be minimized and full operational use expedited

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ENHANCING THE COMPUTER GENERATED ILLUSION

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ABSTRACT

The usefulness of the image produced by a CIG system is not well characterized by just the number of edges or surfaces displayed, but is a strong function of the effectiveness with which the scene details provide visual cues. This paper presents some examples of what can be achieved using hardware capabilities and modeling techniques to enhance the ability of the CIG to present useful scene detail.

Previous CIG systems changed scene details when their image size was small enough so as not to be distracting to the observer. Recently introduced system capabilities allow scene details to evolve in a more continuous, smooth, and independent manner. By using these capabilities, details need not be included in the scene until they are of visual importance. A hierarchical management structure is utilized to provide efficient data base culling and level of detail control. This enables data bases with thousands of square miles, many levels of detail, and thousands of surfaces per square mile to be processed efficiently by the image generator. Such data bases, rich in two- and three-dimensional textural features, can be efficiently produced by using automated generation procedures that require a minimum of modeler effort.

INTRODUCTION

The imagery produced by a real-time computer image generator (CIG) is, in truth, a very sophisticated illusion. The participant in a simulation exercise should feel, think, and react as if what he is seeing is real, when in fact it is not. As the range of training, engineering, and test environments broadens and the demand on training effectiveness increases, so does the demand on the CIG.

The problem for CIG systems has always been to produce the "most effective image" possible within a set of constraints. The typical measure used to define the "most effective image" has been the number of edges or surfaces that can be displayed. This has proven to be an inadequate metric in specifying the capability of a CIG system. The effectiveness of the illusion is more dependent on the system's ability to provide sufficient cues for a particular task, whether it be high altitude navigation or low altitude weapons delivery. This ability can be measured in terms of the number of displayed edges or surfaces, the number and density of cues, the concentration of cues where they are most important, and the system's ability to manage the data base in a manner that is both non-distracting to the observer and efficient in presenting scene detail.

To enhance the computer-generated illusion, an effective combination of modeling strategies and image generator capabilities is required. The development of the techniques presented in this paper was done on an Evans & Sutherland CT5A image generator. This paper will introduce some of the system capabilities, and the modeling strategies which have been developed to more fully utilize these capabilities.

HARDWARE FEATURES

This section will outline the structure of a CT5A data base and then discuss some of the features of the CIG's cell processor, which does the initial processing of the data base.

Data Base Structure

A CT5A data base is a collection of scene elements that has been organized into a hierarchical structure to allow efficient processing by the image generator. Scene elements consist of planar surfaces, called polygons, and lights. Objects in a data base are made up of a collection of these surfaces and lights. Usually an object is thought of as a single entity such as a tree, bush, or rock. By organizing surfaces of various sizes and shapes the modeler can create complex items, such as aircraft and ships. The modeler can determine the visual attributes of an object by specifying the color and shading characteristics of the surfaces that comprise the object. CT5A also allows objects to be made transparent, and several levels of transparency are provided.

The hierarchical structure of the

data base can be likened to a tree with main branches that diverge into smaller branches and eventually down to the individual leaves. The CT5A image generator traces through the data base tree and applies a series of culling tests to determine which portions of the entire data base should be considered for further processing and possible display. These culling tests are performed to eliminate, as early as possible, and in pieces as large as possible, those portions of the data base that will not appear in any display channel. These culling tests include level of detail (only the simplest representation of an object necessary for a given viewing distance is used) and field of view testing (does the item impinge on any display channel). An example of this data base tree tracing will illustrate this concept.

Imagine a data base which consists of the entire continental United States. If the simulated eyepoint is positioned so as to be looking directly at the Evans & Sutherland building in Salt Lake City, Utah, then the image generator must trace through the data base tree for the whole United States and decide which surfaces, out of the billions possible, should be displayed to represent this scene. At the beginning of the tree processing the entire continental United States is represented by what is known as a cell. A cell is a volume in 3 space which has a high and a low level of detail (LOD), i.e., a complex and a simple representation. Each representation may either be an object, which is output directly to the geometric processing function for eventual display, or a collection of cells. This collection of cells, called a mesh, forms another branch of the data base tree which is further processed by the image generator. Each cell also has an associated transition range, which tells the image generator which LOD to process, depending on the eyepoint's distance from that cell.

Since the simulated eyepoint is within the cell for the United States, the high LOD option is pursued and all processing on the low LOD stops. The high LOD for this United States' cell may consist of a mesh of 48 cells, where each cell represents a state. The culling tests are applied to these 48 cells to determine that only the cell for the state of Utah is within the specified transition range and needs further processing, while the other 47 states need no longer be considered. The cell for Utah also has a low and a high level of detail with an associated transition range. The high LOD is processed further by the image generator since the eyepoint is within the specified transition range. This high LOD is made up of several counties in the state, with each county being a cell. Again the culling tests on these county cells are applied to find that only Salt Lake County needs further processing.

Each of the cities in Salt Lake County may be considered a cell with its own high and low level of detail. Since the eyepoint is in Salt Lake City, the high level of detail for the city is processed further while the lower levels of detail for some of the nearby cities may also be processed. The Salt Lake City cell may have several subcells for sections of the city, and again the culling tests would choose the East Bench area for processing at its high LOD, while other portions of the city might have their lower levels of detail represented depending on their distance from the eyepoint. Tracing through the data base tree in this manner continues until the particular scene that is being observed is culled out of the rest of the features in the East Bench portion of the city.

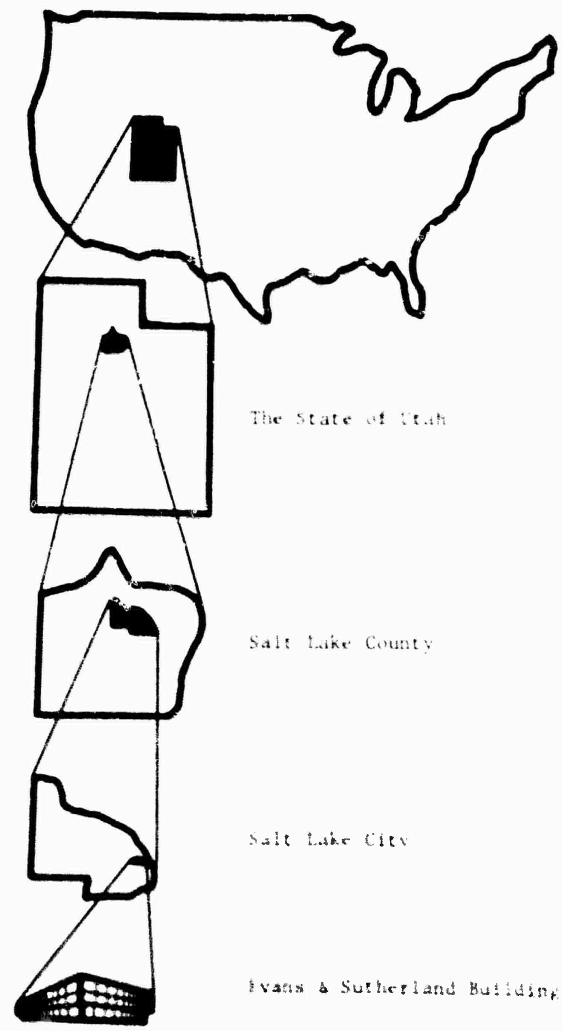

Figure 1
A Hierarchical Data Base

In this manner the image generator has, with very few decisions, culled through the entire United States data base to determine exactly which surfaces need to be processed to display the desired building and nearby details. This type of hierarchical structure allows the CT5A hardware to trace through an extremely complex data base tree very rapidly and efficiently.

The Cell Processor

The cell processor is that portion of the image generator which traces through the data base tree, once every field, to determine which set of objects should be considered for further processing. Several features in the cell processor enhance its ability to perform this function.

Perspective Foreshortening Correction. When a primarily flat scene detail is viewed at a very shallow glancing angle, its effective screen subtense may be much less than its nominal perspective size based on range alone. This perspective foreshortening means that the displayed visual significance of the item will be generally less, sometimes much less, than if it were always viewed straight-on. CT5A provides a method of accounting for the perspective foreshortening of items by correcting the computed transition range to delay introduction of an object into the active scene to provide for equivalent visual impact at the switch. This process helps avoid the compression of details at the horizon, and their attendant buildup, and further frees IG resources for use on more visually significant scene details.

Fade Level Of Detail. Fade level of detail makes the transition between levels of detail smoother and less distracting to the observer. When this is used, the transition is done gradually. Using the transparency feature, the incoming object starts out transparent and becomes more opaque, while the outgoing object starts out opaque and becomes more transparent. This gradual switching between levels of detail allows the transition to take place much closer to the observer without being distracting.

Load Management. The CT5A employs a hardware-based load management scheme which takes advantage of the fact that small modifications in LOD transition ranges throughout a data base can have a considerable effect in altering the image generator's system load, without having a significant effect on the visual scene. The transition ranges on each cell in the data base are modified to keep the image generator running at or below the nominal time. Modifications to the transition ranges are done in real time and are small enough to reduce the system load when necessary without becoming visually apparent. Since the load management is an automatic process, the modeler does not need to be concerned about creating a data base that will never overload the system, he only needs to have a data base whose average complexity is within the system's limits.

MODELING TECHNIQUES

The characterization of what constitutes a useful image has always been a very difficult task. Many considerations must be taken into account which are highly dependent on the training task, the image generator's capabilities, and the subjective bias s of those using the system. There are, however, several objective measures that can aid in determining the usefulness of a data base.

1. How many scene elements can be displayed in each channel, and in the aggregate channels? This number, which is hardware-dependent, has typically been the measure of a CIG's capability, yet important issues arise about how those scene elements are used to provide cues.

2. What is the density of scene elements or objects in the modeled environment? The density of objects in the scene indicates the frequency of cues and determines whether sufficient information can be presented to perform a particular task. Training tasks, such as nap of the earth helicopter flying, may require some type of ground object every 25 feet, while medium altitude flying might require one every 2000 feet. Some tactical missions require appropriate cues throughout a large altitude range, implying a capability to make a graceful transition to additional detail at lower altitudes without exceeding the system's capacity at the higher altitudes. The user of a simulator must determine the density of cues needed for the task and then specify an image generator and modeled data base which can support that density.

3. What is the average density of scene elements or objects in the image plane? Because of scene compression near the horizon, a data base that has a uniform distribution of objects in model space will not be uniformly distributed in the image plane, but will tend to have increased density with distance from the eye. This tends to "crowd" the objects in a very narrow band near the horizon, at the expense of sparser detail closer to the observer. Methods that can create a nearly constant density of objects in the image plane will allow much more visually effective use of scene detail.

4. Are objects provided at various sizes so that cues are available at several ranges from the eye? The eye has a tendency to ignore visual cues from objects which are either too large or too small. Whatever the actual size of an object, there is a range of distances in which the object will have the proper perspective size to be of visual significance, and outside of which the object will be increasingly ignored. This implies that the data base must provide cues which are of various sizes so that those objects, which are larger and spaced less frequently, are mixed in with small items which are spaced closer together. This provides a fairly constant spatial frequency of cues for the participant in a visual simulation.

Several modeling techniques have been developed to increase the effective scene content of a data base based on the criteria set forth above. These methods can provide ways of analytically designing and then producing a data base which will satisfy a broad range of training tasks.

Level Of Detail

The modeler uses a level of detail strategy to create several representations of an object, each with a different number of scene elements. For example, an airplane might have three levels of detail, i.e., three representations, one with 440 surfaces for the highest detail, another with 140 surfaces, and the lowest detail may only be 32 surfaces. The image generator chooses which representation to display based on the distance from the eyepoint to the airplane. In creating the data base, the modeler specifies that the airplane will first appear as the lowest level of detail at 3.25 nm., then be replaced by the middle level of detail at 0.5 nm., and the highest detail representation will be shown at 0.1 nm.

The modeler tries to specify transitions to take place as close as possible without making the replacement distracting, and thus saves the image generator as much processing as possible. The distance at which the transition takes place is based on such criteria as: 1) the perspective size of the object, 2) the relative contrast between the object and its background, 3) the shape of the object's silhouette, and 4) the relative geometric differences between the levels of detail which are switching. By using simpler representations for objects at greater distances, the image generator has greater capacity to display more objects, thus increasing the number of visual cues that can be displayed.

The level of detail strategy applies not only to individual objects but also to every cell in the data base. Each cell in the data base has a low and a high option pointer which can be considered the low and high levels of detail for that cell. This allows an entire region to have a low and a high detail representation, as well as each portion of the region. The real power of the strategy comes from the hierarchical nature of the cell. By creating a hierarchy of cells, the modeler can create a tree with a high and low level of detail, then a group of trees with a high and low level, then a forest with a high and low option, and even an entire large section of forested terrain with both options.

An example of this can be seen in Figure 6. Represented in the desert scene are six levels of detail. The first level of detail consists of the basic desert floor with a few mesas. Nearer to the eye, buttes are added to form the second level of detail and complete the large objects. The third level of detail is formed by adding sand dunes around the mesas and buttes. These dunes are added to the scene at a distance which makes their silhouette visually significant. The fourth level of detail is to add the cacti on and around the dunes and buttes. The fifth level of detail adds the bushes to the scene. Rocks and pebbles make up the sixth level. This six level-of-detail design of the desert applies the level-of-detail ideas to the desert as a whole, as well as to each palette item in the desert, and makes the scene very detailed near the eye but fairly simple far away where the small items are not important.

Fade Level Of Detail

With the hardware fade level-of-detail capability, the modeler has greater leverage in specifying the transitions between representations of an object. Previous strategies for level of detail switching required a sudden replacement of one representation for another. This required the switch to take place when the perspective sizes of the objects, or their relative differences, were sufficiently small so as not to be distracting to the observer. This was typically at a much greater distance than that at which the resulting details were useful. Thus a significant amount of detail had to be processed, not because it was useful but solely to help keep its introduction from becoming objectionable.

If fade level of detail has been selected by the modeler for the transition between an object's two levels of detail (LOD), then at the specified transition range the replacement LOD is brought into the active scene as a transparent object. As the distance from the eyepoint to the object changes the replacement LOD gradually becomes more opaque while the replaced LOD becomes more transparent. When the replacement LOD is fully opaque the replaced LOD is completely transparent and is removed from the active scene.

Fade level of detail makes the changes between objects more subtle and consequently less distracting to the observer, and thus allows the transitions to take place closer to the observer. The subtlety also enables the use of fewer levels of detail, with greater geometric differences between levels, yet still without distraction at transition. Fifty percent reductions in the transition range are not unusual. This means that simpler representations are more often displayed, which conserves system resources and allows more objects to be displayed.

Level Of Scale

A visually effective data base must provide a selection of visual cues of differing sizes and spacing. Each particular visual cue has a range over which it contributes significantly to the image; beyond this range its decreasing size makes it less and less valuable, and the modeling strategy should remove it from the scene when its value drops below some threshold. To extend the scene richness beyond this range, other visual cues are needed which are substantially larger (hence continue to have visual significance at the further ranges), and are spaced farther apart. Several additional leves of scale may be provided, each with a particular range over which it contributes significance, until a continuity of detail to the maximum required range is achieved. The largest levels of scale, which are introduced into the scene at the longest ranges. are not removed from the scene as the observer gets close to them, but their greater spacing keeps their contributions from overloading the image generator. Each level of scale can be designed to require a percentage of the overall image generator resource, and then several levels added together to achieve the required depth of scene without image generator overolad. The desert shown in Figure 6 uses six such levels of scale, and achieves scene richness from very near the observer out to ten miles. The apparent scene density remains high over a wide range of flight altitudes, and the emergence of the smaller levels of scale provides valuable velocity, altitude and time-to-impact cues.

Computational Methods

Planning and executing the design of a data base to accomplish specific objectives within given image generator constraints has traditionally been a difficult and iterative task. The next few sections of this paper indicate how such planning and estimating can be successfully accomplished during the design phase, and how the data base structure makes it feasible to modularize the modeling process. In performing these computations, several approximations are made concerning the data base and the methods used in deriving the results. The data bases used in these examples are assumed to be sufficiently flat that the surface area of the terrain can be approximated by a plane and planar area formulas can be used. When the area under consideration extends from the eyepoint out to a particular distance, the area will be computed as a sector of a circle. If the area under consideration is bounded by two nonzero distances from the eyepoint, then the area will be computed as a sector of an annulus. The average ground area per object is computed as the total area covered by the objects divided by the number of objects in that area. The average spacing between objects is simply the square root of the average ground area per object.

The hierarchical nature of the data base tree allows the modeler to construct the data base in modules which can then be concatenated to form the whole data base. The impact of each module on the image generator's capacity can be computed independently from the other modules in the data base. As the modules are joined to form larger modules, the result on system load is additive. This allows the modeler to start with the specifications for a data base and systematically budget the image generator's resources among various types of detail to produce the desired data base.

The arithmetic used in deriving the results of the next few sections is simple and straightforward. Sufficient information is provided so the reader can verify the numbers if desired.

Scene Element Densities In Model Space

Computing scene element densities gives an indication of the number of visual cues presented in a scene as well as their average spacing. If the data base is assumed to lie essentially in the ground plane, then scene element density means the number of scene elements per square unit when the highest level of detail for objects in the area is presented, e.g., surfaces per square nautical mile (sqnm). This is usually computed as:

$$\text{Density} = \frac{\text{No. of objects}}{\text{sqnm}} * \frac{\text{No. of surfaces}}{\text{object}}$$

Because of the limited capability of an image generator to display scene elements, the allowable density of objects in a data base is constrained by the total number of scene elements which can be processed and the simulator's field of view. In the following examples the visual system is assumed to have a 120-degree horizontal field of view.

The above relationship gives the modeler four parameters which can be adjusted to meet the needs of the simulation problem: number of objects, the area which is covered by the highest level of detail of these objects, the number of surfaces per object, and the density. Any three of them necessarily define the fourth.

Typically a modeler will be faced with a problem where one or more of the parameters will be specified for him and he must create the data base to fulfill those specifications. A problem a modeler might encounter is to create a forest which uses an average of 1500 surfaces for the trees within the field of view. The next task the modeler would do is to design a tree or several types of trees which he would like to put in the forest. The modeler can make a tree which uses anywhere from several hundred surfaces to a simple three-sided pyramid in its highest LOD; the choice is based on the visual requirements for the simulation exercise. Some situations, such as nap of the earth helicopter flying, may require very detailed trees, while other applications for higher altitudes may be satisfied by simpler representations. The specifications for the data base should indicate the types of visual cues required. Suppose that in this example the forest will be flown over at a high velocity and only fairly simple representations for the trees are needed to give height and velocity cues. Based on this criteria the modeler creates a tree which has 10 surfaces. After some experimentation the modeler finds that if the tree is added to the active scene at a range of 5 nm., then the audition of the tree is not distracting to the observer.

The modeler has now specified all of the parameters in the density relationship. The area in a 120-degree field of view sector of a 5 nm radius circle is 26.2 sqnm with 1500 surfaces desired. This implies a density of 57 surfaces per sqnm or 6 trees per sqnm. This density means that the average ground area per tree is 6.44 million sqft. or an average spacing of 2,500 feet between trees. The modeler can then create his data base so that the placement of trees in the forest is an average of every 2,500 ft.

By using fade level of detail, the transition range at which the tree is added to the active scene can be decreased considerably. If in the above example the transition range were to be decreased to 1.5 nm., then the resultant forest would have an average surface density of 637 surfaces per sqnm. or 64 trees per sqnm. with the average spacing between trees being 762 ft. The tremendous leverage that is gained by decreasing the transition range is due to the fact that the total area displayed at a given LOD decreases proportionately to the square of the transition range.

Using multiple levels of detail also gives the modeler tremendous leverage, since representations requiring fewer surfaces can be used for the sections of the field of view which may cover large areas. Suppose the modeler finds that he can create a lower level of detail for the tree which uses only 3 surfaces. The modeler also changes the transition ranges so the low level of detail comes in at 1.5 nm. and the high level of detail comes in at 0.25 nm. Using these parameters, the modeler computes that his forest can now have a surface density of 1,992 surfaces per sqnm. or 199 trees per sqnm. with an average spacing between trees of 430 ft.

Table 1 summarizes the results of these three examples and shows the tremendous increases in surface densities realized when using multiple levels of detail and the fade level of detail option.

Tree Configuration	Average Spacing between trees (ft)	Polygon Density (surfaces /sqnm)	Tree Density (trees /sqnm)
1 level of detail, 5 nm. transition	2,500	57	6
1 level of detail 1.5 nm transition	762	637	64
2 levels of detail, 1.5 and 0.25 nm transitions	430	1,992	199

Table 1
Forest Tree Surface Densities

Image Plane Scene Element Densities

If the density of objects in model space is constant, as in the examples above, the density of objects in the image plane will increase with the distance from the eye. This is simply because the area in a given section of the image plane increases with that section's distance from the observer. This tends to concentrate the objects in a scene close to the horizon and leave fewer objects close to the eye. To efficiently use the displayed objects for visual cues, the observer would like to have the density of objects remain constant in the image plane so that the number of objects close to the horizon is nearly the same as it is close to the eye. This implies that the density of objects in model space must decrease rapidly with distance from the eye.

When computing the image plane density the modeler needs to know the vertical field of view configuration for a simulator. Figure 2 shows a possible configuration.

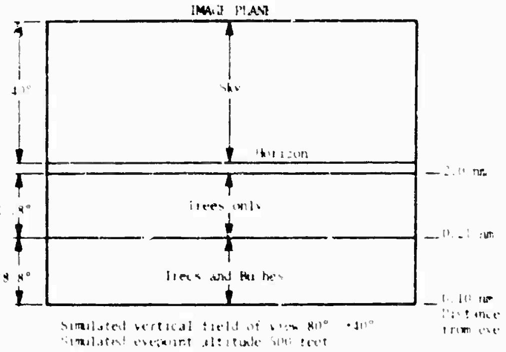

Figure 2
Vertical Field Of View Configuration

To achieve near constant image plane density, the modeler can employ some of the level of scale concepts and add smaller objects close to the eye at a greater density to provide more visual cues. Continuing with the example above of the forest, the modeler may wish to add bushes to the foreground half of the image plane section covered by trees, i.e., the section covered by angle A in Figure 2. Suppose that the modeler has created a bush which has a transition range to be brought into the active scene of 0.21 nm. The modeler then needs to compute the necessary density of bushes to have the same image plane density in the area with trees and bushes as in the area with trees only.

The density of trees in the 120-degree horizontal field of view was previously computed to be 199 trees per sqnm. The area covered by the annulus defined by angle B in Figure 2 is 4.1 sqnm., hence 825 trees are in that section of the field of view. The region defined by angle A in Figure 2 has an area of 0.04 sqnm. To achieve the same density of objects in the section of the image plane covered by angle A, there must also be 825 objects. In the region covered by angle A there are presently 7 trees, which means that the modeler needs to add 818 bushes to achieve the desired object density in the image plane. 818 bushes spread out over the area covered by angle A would be achieved by placing a bush on the average of every 40 ft.

With the addition of the bushes to the foreground, the modeler has achieved either a bush or a tree approximately every 40 ft. as compared to th 430 ft. with only the trees. If the modeler uses 4 surfaces for the bush, then he will have achieved a surface density in the forest of approximately 93,673 surfaces per sqnm.

The 93,673 surface density represents the total number of surfaces which comprise all of the bushes and trees when their highest level of detail is presented. Since the trees have a lower level of detail and not all the surfaces in the bushes and trees are front-faced, only about 4000 surfaces are actually displayed.

Another technique for achieving a near constant image plane density is to have the same type of objects brought in to the active scene at varying distances. In the forest example the modeler may choose not to use bushes, but rather have the trees brought into the scene at several transition ranges. He may have trees coming in at 2 nm., 1 nm., and 0.5 nm., each with increasing densities in model space as the distance from the eye decreases.

By trying to achieve a constant image plane density, the modeler can create a data base which has an abundance of three-dimensional cues near the eye where they are useful instead of concentrating them on the horizon. These examples, although simplified, show the basic principles. In practice the modeler can calculate the densities of several sections of the screen and use several different types of objects to achieve the desired densities.

<u>Automated Generation Procedures</u>

In the creation of high density data bases, the modeler is faced with the problem of how to create the large number of objects necessary. In the above example of the forest with bushes, if the modeler were to create each individual bush and tree in a 50 nm. x 50 nm. square of forest he would have to make about 57 million bushes and 500,000 trees. The need for automated creation of objects is clearly evident. It is also evident that the image generator must be able to reuse portions of the data base since it cannot hope to store the number of surfaces required for each individual tree and bush.

The modeling system used to create CT5A models has a procedural capability, which gives the modeler tremendous leverage in creating large numbers of similar objects. These procedures are somewhat similar to FORTRAN subroutines which have input parameters and particular outputs. A procedure which makes a tree can have input parameters of position, scale, rotation, and transition ranges between levels of detail. Once the procedure is written, it can be called many times with variations to the input parameters to create a large group of trees. After this group of trees has been made, it can be duplicated and used in many locations to create a whole forest.

The creation of terrain over large geographical areas is greatly aided by the use of procedures. Procedures can be written to create mountainous areas, hills, farm land, forests, swamps, oceans, and the like. If the modeler is constrained to create a section of terrain to a certain level of specificity he may do so and then continue the enhancement of the terrain by the use of procedures. A modeler may specify where the major peaks, valleys, and ridges are in a mountainous section and then let the procedures embellish the basic structure with smaller hills, minor peaks, and vegetation.

Procedures defined in the modeling system may, of course, call other procedures. This capability gives even more leverage to the modeler. A procedure may be written to do a runway by calling other procedures to do VASI's, runway lights, strobes, stripes, numbers, oil marks, tire marks, and expansion joint cracks. In this manner a modeler may build an entire runway in only a few minutes by specifying such things as runway heading, length, and type.

The large number of surfaces, which must be stored and processed in a high density data base, also requires the image generator to be able to reuse portions of the data base. The CT5A has an instancing capability which allows portions of a data base to be stored in memory once, but used many times by relocation within the data base. The modeler uses this instancing capability by creating a mesh for a particular portion of the data base and then indicating that copies of this mesh should be placed at various locations in the visual environment. The original mesh is placed in the image generator's visual environment memory and then all copies access the same information from memory and apply a modeler-specified translation to position the mesh where desired.

When creating the forest, the modeler may create a group of 575 bushes and 5 trees as a mesh. Using the instancing capability, the modeler may then place this group of bushes and trees at various locations to create portions of the forest or perhaps the entire forest. This small section of forest could be used in the data base as needed. In this manner the modeler only has to model a small section of the data base to get effectively large sections, while freeing the image generator's memory to hold more information concerning other portions of the visual environment.

EXAMPLES

This section shows several examples of data bases which have been created to demonstrate the modeling strategies discussed above. These data bases are all designed to run on a six-channel CT5A with a 120-degree horizontal field of view and to stay within the system's nominal capacity.

Figure 3: Hilly forest -- This hilly forest employs a single seven-surface object for the trees, using fade level of detail for the transition from null to a single tree. The trees are brought into the scene at distances ranging from 1.5 nm. to 0.5 nm. to maintain a constant image plane density. No level of scale concepts are employed, hence the lack of cues for higher altitudes or for below tree top flying. The spacing between the trees is approximately 191 ft., creating a surface density of approximately 7,000 surfaces per sqnm.

Figure 4: Flat Forest -- The flat forest employs two levels of detail for the trees and employs fade level of detail for the transitions. Constant image plane density is achieved by varying the distance at which the trees are brought into the scene. The trees and the abstract ground patterns create two levels of scale and enable flight below tree top level. The surface density achieved here is approximately 130,000 surfaces per sqnm. with a spacing between the trees of approximately 50 feet.

Figure 5: Ocean and Clouds -- Textural features like ocean waves and clouds are possible using several levels of detail and several levels of scale on the color patterns. The procedures used in creating the ocean and clouds are similar and required the modeler to specify only 28 surfaces for the patterns. The ocean and clouds have been designed to use only 34% of the system channel capacity, thus reserving sufficient capacity for ships and aircraft.

Figure 6: Desert -- The desert represents the most thorough application of the modeling techniques. Six levels of scale are used to create a nearly constant image plane density and to support flight at a broad range of altitudes. Each item in the desert is

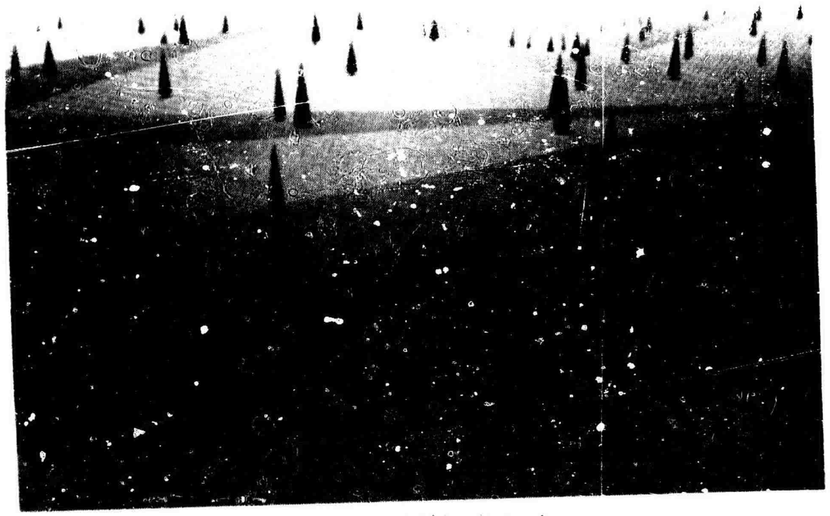

Figure [illegible] Forest

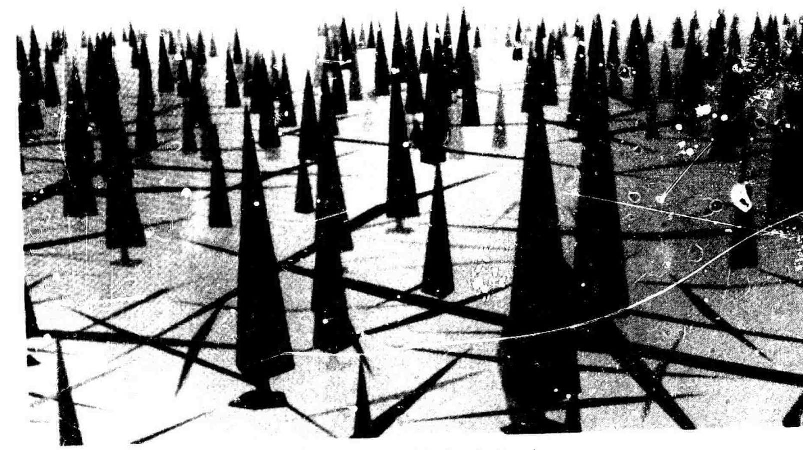

Figure [illegible] Flat Forest

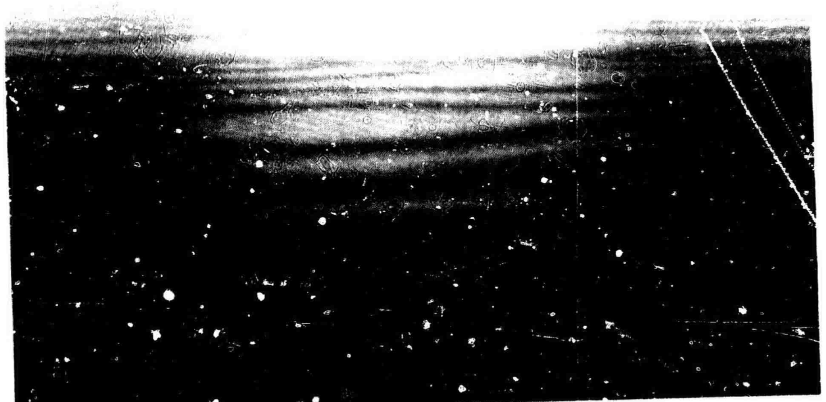

Figure [illegible]

Figure 6 Desert

modeled at 2 to 4 levels of detail, using fade level of detail for the transitions. The surface density achieved is approximately 87,000 surfaces per sqnm. over 100 sqnm. and yet, using the procedural capabilities, the modeler only had to model approximately 400 surfaces. Using the hardware instancing, the entire desert requires only 4000 surfaces in the image generator's memory.

CONCLUSIONS

An effective combination of the CT5A hardware capabilities and modeling strategies enables the modeler to create and display data bases which greatly increase the usefulness of the CIG image. The image generator's ability to process large amounts of information, and make a multitude of decisions concerning such things as level of detail, load management, perspective foreshortening correction, and data base culling in real time, enables the modeling strategies to be employed.

It is our belief that by applying these modeling techniques, along with the necessary hardware support, visual data bases can be created which will support nap of the earth, contour flying, vertical takeoff and landing, and a host of other applications.

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SIMPLIFIED SCENE MODELING USING CURVED SURFACES AND TEXTURING

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ABSTRACT

Constructing a scene data base for current computer image generation systems is a costly and time-consuming task. Thousands of edges must be defined by positioning the end points, or vertices, of each edge. In addition, edges bounding a common surface or face must be linked in a list. Data for each face must include information for a normal vector, and data for faces representing curved objects must include information for normal interpolation to simulate smooth shading across the object. This paper describes a more efficient scene model that is easier to construct and yet produces a more faithful representation of the real world. Scene geometry is modeled by quadric surfaces bounded by planes. Scene detail is modeled by a mathematical texturing function which modulates surface shading intensity and translucence. The paper describes how the new model simplifies modeling terrain, cultural features, moving targets, and special effects.

INTRODUCTION

The problem of constructing a computer model representing the complexity of a real-world scene and allowing real-time image generation is a formidable one. Two decades ago, computer image generation (CIG) pioneers attacked this problem by applying a time-honored engineering axiom: "be wise - linearize." The linear scene model that they produced was defined by efficiency of image computation rather than by efficiency of modeling. Over the past 20 years, impressive developments in CIG techniques based on this model have reinforced its use. Over the same period of time, however, the sophistication and complexity of training missions have created new demands on CIG technology. Ironically, it is the past successes of CIG that have enabled training to move forward to the point where it can make these demands.

Current training requirements call for the capability to model extensive gaming areas and to represent scene detail with enough fidelity to support nap-of-the-earth (NOE) flight and ground based operations. The asymptotic progress of edge CIG technology indicates that these requirements can be satisfied only by a new, more efficient approach to scene modeling.

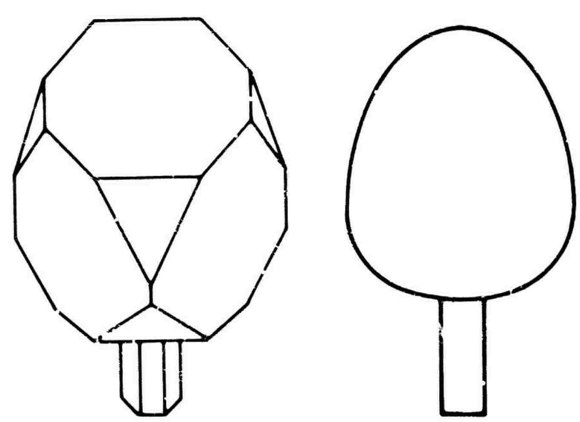
A NEW SCENE MODEL

In developing a new scene model, Grumman studied the problem from the top down, choosing the most efficient data base to represent the full range of scene features needed for today's training. These features include terrain, vegetation, cultural features, moving targets, clouds, smoke, and weapons effects. We determined that the most significant limitations in edge technology for modeling these features were due to its inability to model surface curvature and textural detail efficiently. We therefore focused our scene model development on devising efficient representation of these two features.

Surface Curvature

Quadric surfaces are mathematically the simplest form of curved surface and can represent individual scene features as individual volumes. This allows modeling many scene features, such as a bush or a boulder, by a single ellipsoid. Modeling such features in this way is much simpler than using edges because very few parameters are required to define a quadric surface, and these parameters relate directly to the shape and position of the feature being modeled.

Many scene features can not be represented by a single quadric surface alone. To allow more flexibility in our scene model, we include the capability to bound a quadric surface with planar surfaces[1]. This allows us to model a wide variety of curved and linear scene features in a very simple manner. For example, we can model an aerodynamic surface using a thin elliptical cone bounded by two planes. A gun barrel or tree trunk can be modeled by a cylinder bounded by two planes. We organize our data base as a set of such geometrically defined "objects," with each object defined by one quadric surface and up to six bounding planes. Complex scene features, such as targets, are modeled by multiple objects. A glance at Fig. 1 will show how this parametric approach



(a) EDGE MODEL (b) QUADRIC SURFACE MODEL

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Fig. 1 Comparison of Two Tree Models

simplifies scene modeling compared to edge modeling. Using edges, the foliage for a single tree would require the positioning of many vertices, with lists linking vertices, edges, and faces. Using quadric surfaces, we need specify only three dimension parameters, three rotation angles, and three position coordinates for an ellipsoid, in addition to three rotation angles and three position coordinates for a bounding plane. The tree trunk can be modeled similarly by a cylinder and two bounding planes. Thus, the modeler will be required to define fewer data values, and these values will have a direct relation to the geometry of scene features he is modeling.

The significance of this simplification lies in the fact that any realistic scene will contain hundreds or even thousands of such features. Automated as well as manual scene modeling will benefit from this simplification since less data is involved, and the parametric nature of the data base allows straightforward definition of shape, size, and position.

Textural Detail

Most of the visual detail in real world scenes is due to minor topographical variations that would be very costly to model with a geometric data base. Such detail can be efficiently modeled using texture patterns mapped to the appropriate geometric surfaces. In studying various approaches to texturing, we developed a mathematical function that modulates surface shading intensity as the image is generated[2]. The texture function maps the pattern directly to scene surfaces with true perspective validity because its independent variables are the scene coordinates. This approach produces a very compact data base because only 25 function parameters define complex patterns covering large scene areas. In addition, many scene features can be textured using the same set of parameters. Because the pattern depends on the scene coordinates, each feature will look different from all the others. In this way we can model an unlimited number of individual trees or hills using a single set of texturing function parameters. Because the function parameters can be related to the spectral content of the texture pattern, modeling can be based on Fourier analysis of images of real-world features. Thus, the texture function has the potential for automated modeling.

One of the greatest advantages of the texturing function technique is the ability to control the function parameters on-line during image generation. This permits eliminating any high-frequency content of the pattern that would cause aliasing. Related to this feature is the ability to vary the detail of the pattern as a function of range. This provides a very efficient means of varying level-of-detail (LOD) without changing the geometric data base. Control of the function parameters also allows us to vary translucence across the surface of an object to enhance the modeling capability by simulating irregular boundaries and holes. Finally, by varying the parameters dynamically, we can simulate motion, such as tree leaf agitation and smoke rising.

In summary, the texture function simplifies modeling of scene detail by employing a minimal data base that can be related directly to the visual characteristics of specific real-world features. In addition, the texture function allows an efficient means of modeling irregular features, such as trees, clouds, and smoke, with dynamic capability.

SCENE MODELING WITH TEXTURED, QUADRIC SURFACES

Although quadric surfaces have been recognized as potentially useful for modeling a limited set of cultural features[3], they have generally been considered too simple to model the wide range of features required for combat training[4]. We have found that the limitations of quadric surfaces are greatly minimized by the addition of texturing, and that the combination of quadric surfaces and texturing provides an efficient data base for modeling the full range of features required for training, including cultural features, terrain, and special features.

Cultural Features

Many cultural features can be modeled by a single bounded quadric surface. Cylinders can be used for oil tanks and poles; spheres can be used for fuel tanks, lights of finite size, and radar domes. More complex cultural features can be modeled by sets of objects each consisting of a bounded quadric surface. Thus we can use a single object to model a wing, a canopy, an engine pod, a refueling boom, a tank turret, a gun barrel, a smoke stack, a wheel, or even a helicopter rotor disk. Complicated curved bodies, such as an aircraft fuselage, can be either approximated by a single object or modeled more accurately by multiple objects. In the latter case, care must be taken to fit abutting objects without noticeable surface discontinuities. The simplicity of the mathematics of quadric surfaces provides the potential for automated modeling aids to alleviate this problem. The simplicity of modeling cultural features typical of training scenes is demonstrated in Fig. 2, which shows how a tank can be modeled

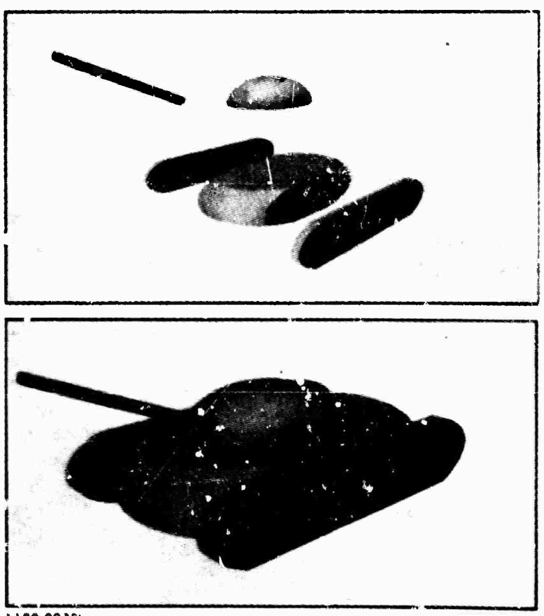

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Fig. 2 Tank Model Compressed of Five Bounded Quadric Surface Objects

efficiently with only five objects. Figure 3 shows a high LOD version of the tank using 51 objects.

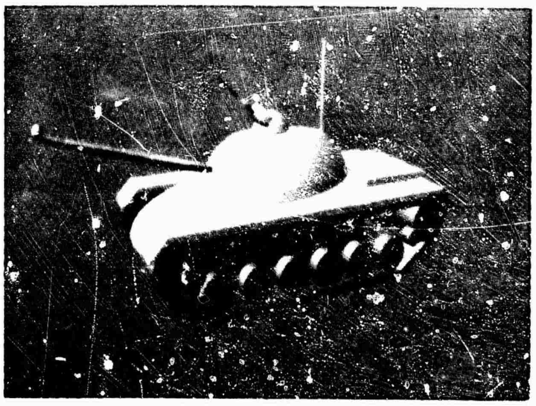

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Fig. 3 High Level-of-Detail Tank Model Composed of 51 Objects

Because each of our objects can include up to six bounding planes, they can be used to model linear, as well as curved, cultural features. To model complex linear features such as factories, we developed a program called "BLOCK," which creates buildings of arbitrary complexity using simple linear objects as building blocks. The building blocks are rectangular solids simply defined by three position and three dimension parameters.

Our texture function can be used to add detail to a cultural feature model. This detail can be linear, as in stripes on building walls, or non-linear, as in camouflage markings on targets.

An important consideration in modeling large gaming areas is implementation of the Defense Mapping Agency (DMA) cultural data information. Because this information defines features in generic terms only, it will be necessary to construct a library of generic cultural features which can be accessed, scaled, and positioned in the scene in accordance with the DMA data. The efficiency of our object modeling will facilitate the construction of such a library, and the parametric nature of the modeling will simplify scaling and positioning the features.

<u>Terrain</u>

The task of modeling arbitrary terrain has generally been approached by treating an extensive region as a single, complicated surface that can be approximated by a large number of planar patches. Because a linear model is so inefficient for modeling complex curved surfaces, an unacceptable number of edges would be required for a realistic representation. As a result, real-time edge systems must limit the edge allocation and produce primitive terrain images dominated by sharp linear boundaries.

A more efficient and effective way to model terrain is to represent it as the eye perceives it, as a set of individual topographical features, such as hills, mountain peaks, and ridges. Quadric surfaces lend themselves to this approach because each major feature can be modeled by a single curved surface free of linear artifacts. The quadric surface can be defined by 10 parameters specifying its shape and orientation in the scene. Although isolated quadric surface objects can be used to model some terrain features, in general, clusters of abutting objects will be required to provide a satisfactory representation of arbitrary terrain. This requires determining appropriate bounding planes to provide continuity between adjacent quadric surfaces. Figure 4 shows schematically how single or multiple quadric surface objects can be used to model terrain features.

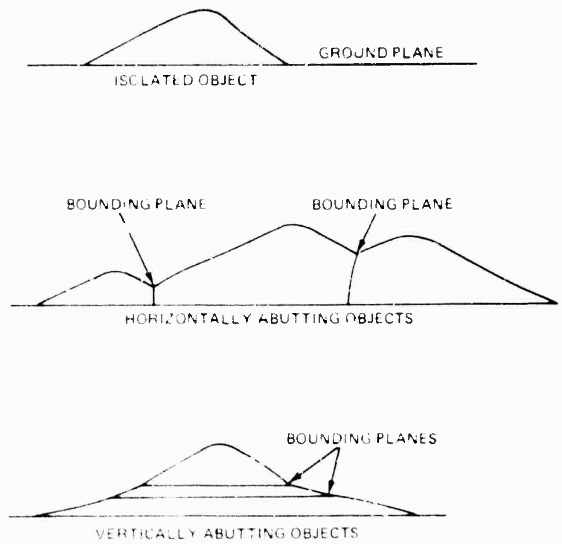

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Fig. 4 Examples of Terrain Features Modeled by Single and Multiple Bounded Quadric Surface Objects

Modeling the significant terrain features with quadric surfaces will produce a very compact data base free of linear artifacts, but will not by itself provide enough scene content for training. Our texturing function will produce the textural detail required to model the secondary topographical detail common in real-world terrain. A single texture pattern, defined by one set of texture function parameters, can be used to texture all surfaces, including the ground plane, within a defined region of arbitrary size. This provides a great deal of scene content with a minimal data base. In addition, the texturing enhances the appearance of surface continuity in the scene. Because we model major terrain features individually, we can also assign different texture patterns to different features. This will allow us to represent grass-covered hills, rocky mountains, and forest areas in the scene.

To satisfy the requirements of training missions involving low-level flight and ground-based operations, we must be able to model ground features, such as trees and rocks, with a fair amount of realism. Trees have been a particular stumbling block in edge modeling because edges define features in a very explicit manner. Thus, hundreds or even thousands of edges would be required to represent the complexity of a tree's foliage. Using quadric surfaces, we can model a tree with one or two textured objects. The parametric control inherent in our texturing function provides the irregular surface and boundary detail necessary to represent the essence of tree foliage without explicitly modeling each branch and leaf. An added advantage to this approach is the fact that the texture intensity is added to the quadric surface shading intensity. As a result, the overall shading of the model is representative of the illumination source, with "leaves" on the underside darker than those on top. In a similar manner, rocks and boulders can be modeled accurately by a single textured quadric surface for each.

To take advantage of quadric surface modeling of terrain features, we developed a computer program called "CNGEN" which generates clusters of hills, trees, and rocks. CNGEN operates on a very compact list of feature clusters. The data for each cluster include:

(1) coordinates and dimensions of a rectangular region on the scene ground plane and a grid spacing for positioning individual cluster features in the region,

(2) shape, and relative position parameters for template objects representing a typical cluster feature,

(3) an index to a list of texture function parameter sets,

(4) a set of three color parameters (RGB), and

(5) a translucence value.

For each cluster in the list, CNGEN adds pseudo-random increments to the grid position, color, and shape parameters of each individual feature and stores the features in a scene data base list. CNGEN greatly simplifies creating a terrain model of a large gaming area, and editing the scene is facilitated by the capability to change the position, extent, or character of a large number of objects at once. Different texture patterns or colors can be specified as well as different shapes and sizes for cluster features. Because of the efficiency of quadric surface modeling, the computation involved in CNGEN is minimal, suggesting the feasibility of on-line scene generation.

The simplicity and effectiveness of textured quadric surface modeling are demonstrated in Fig. 5 and 6. Figure 5 shows a terrain scene composed of quadric surfaces without texturing. Figure 6 shows the same scene with texturing. This model was generated by CNGEN from a list of 18 feature clusters defined by a total of 400 data values. The texture parameter file included data for seven texture patterns defined by a total of 175 data values. The final model included 173 objects, many of which are not visible in the image. We generated a dynamic sequence of NOE flight through this scene which confirmed the perspective validity of the modeling approach and demonstrated excellent flying cues produced by the high scene content.

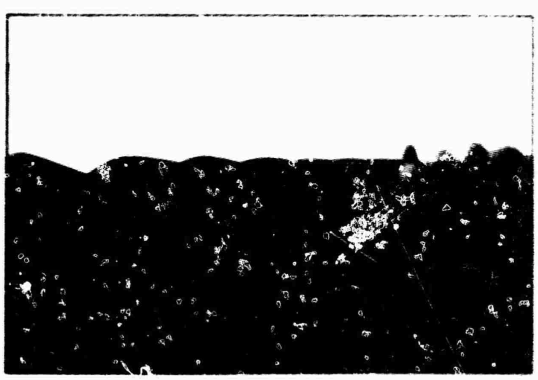

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Fig. 5 Terrain Scene Composed of 173 Bounded Quadric Surface Objects Without Texture

1199-006D

Fig. 6 Terrain Scene Composed of 173 Bounded Quadric Surface Objects with Scene Detail Produced by Texturing Function

To provide full terrain modeling capability for today's training requirements, we will have to use the DMA elevation data as a primary source. We have performed preliminary research in this area and have developed an approach to modeling the DMA data with textured quadric surfaces. This approach includes the following steps:

(1) Determine major terrain features by low pass digital filtering of the DMA elevation data.

(2) Isolate major features in the filtered data using digital image processing and pattern recognition techniques.

(3) Fit a single quadric surface to the original DMA data corresponding to each isolated major feature.

(4) Determine appropriate bounding planes for each feature to maximize continuity between adjoining surfaces.

(5) Determine appropriate texture function parameters by Fourier analysis of the original DMA data.

Under a National Science Foundation (NSF) grant we investigated the feasibility of our approach by means of a two-dimensional analysis in which we filtered profiles of actual digitized elevation data, isolated peaks, and fit conic section curves[5]. The success of this work provides a firm basis for extension of the techniques to three dimensions. Terrain models generated in this fashion will produce a realistic, nonlinear data base that will greatly compress the information contained in the DMA elevation files. Our CNGEN techniques will then be extended to enhance the terrain elevation model by adding trees, rocks, and other surface objects.

Special Features

Although the great majority of scene objects can be modeled as solid objects with clearly defined boundaries, today's military training scenarios include scene features, such as weapons blasts, smoke, dust, and clouds, which can not be represented in the same explicit manner and must be treated as special features. These features are characterized by a lack of solidity and by amorphous shapes with irregular and poorly defined boundaries. In addition, they are generally dynamic, with constantly changing structure. Although these features are serious stumbling blocks for edge modeling, they are very efficiently modeled by textured quadric surfaces. Just as we modeled the foliage of a tree using a single textured quadric surface with variable translucence, so we can model a column of smoke, an atmospheric cloud, a dust cloud, or a weapon burst. Control of the texture function parameters allows the variable translucence required to simulate an amorphous shape. In addition, we can vary the parameters from frame to frame to agitate the texture pattern to simulate motion. The simplicity of quadric surface shape definition even allows us to create expanding weapons bursts.

Some of the possible special features that quadric surfaces can model effectively are shown in Fig. 7 and 8. Figure 7 shows smoke from chimneys on a factory. The clouds in the sky are modeled by mapping texture onto a plane in the sky. Figure 8 shows tanks with dust clouds. We generated a dynamic sequence of this scene which demonstrated the realism of the motion of the dust. The effect was produced by moving the quadric surfaces assigned to the dust clouds with the tanks, while moving the texture pattern on the dust objects at a slower speed. Figures 7 and 8 also demonstrate the modeling of textured linear features (the factory), textured targets (the tanks), rolling terrain, rocks, and bushes.

ADDITIONAL ADVANTAGES OF THE NEW SCENE MODEL

The sophistication of modern training scenarios places stringent demands on scene modeling for CIG systems. Viewable scene content must be carefully managed to prevent system overloads due to excessive computation loads during image generation. Specific enemy targets must be modeled with enough fidelity to allow recognition at reasonable distances, and provision must be made to allow targets to move arbitrarily in the scene.

Scene Management

Modeling scene features in multiple levels of detail has proven to be an effective means of controlling scene content. But this technique impacts the scene modeling task by requiring features to be modeled several times. Modeling with textured quadric surfaces simplifies the implementation of LOD modeling in three ways.

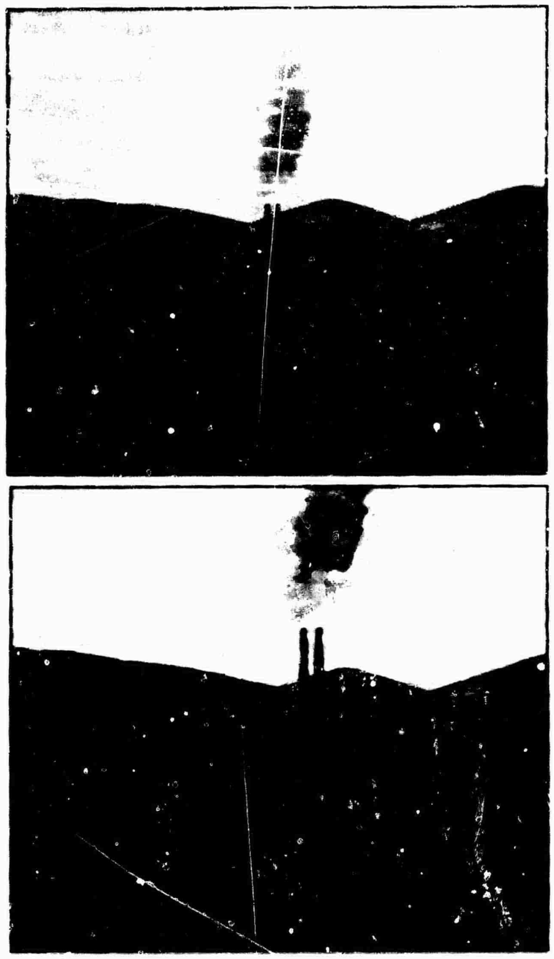

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Fig. 7 Terrain Scene Including Factory and Smoke Modeled by Bounded Quadric Surface Objects and Texturing Function

First, many scene features can be modeled in a single LOD using a single textured quadric surface. Control of the texture function to eliminate high frequency detail that would produce aliasing automatically provides LOD management. Thus the same model can be used regardless of the viewing range. Second, large clusters of individual scene features, such as groups of trees, can be modeled in just two levels of detail, a high LOD model consisting of objects representing the individual features and a low LOD model consisting of one object representing the cluster. By inserting a moveable bounding plane at a fixed distance from the viewpoint, we can continuously truncate the low LOD object as the viewpoint approaches while smoothly inserting the high LOD objects in front of the bounding plane. As shown in Fig. 9, this technique will be effective for low altitude approaches that would not lend themselves to a simple fading of the low LOD object by increasing its translucence. This technique has the added advantage that translucence need be applied only to the high LOD objects near the bounding plane to smooth the LOD transition. In addition, texturing will greatly enhance the effectiveness of both LOD models. Finally, the simplification in modeling provided by textured quadric surfaces will apply to all levels of detail. Thus even features requiring more than two levels of detail will be easier to represent.

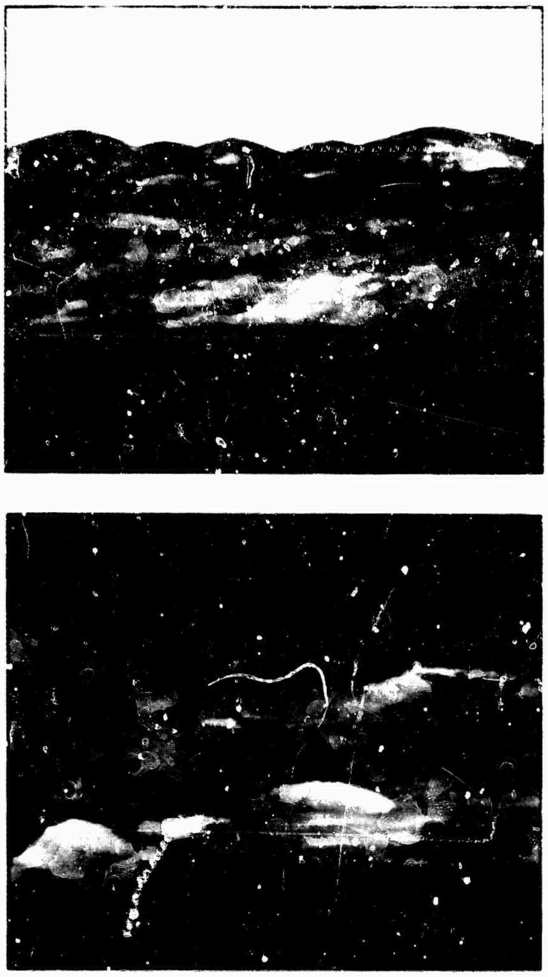

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Fig. 8 Camouflaged Tanks with Dust Clouds in Rolling Terrain Modeled by Bounded Quadric Surfaces and Texturing Function

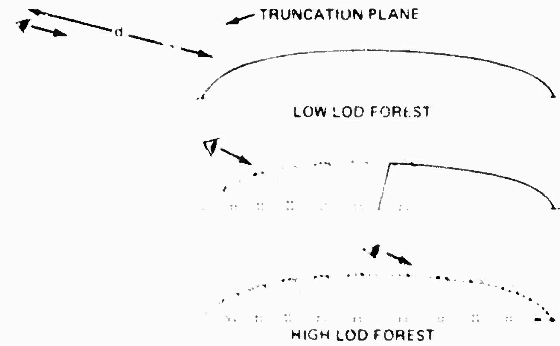

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Fig. 9 Transition Between Low and High Level-of-Detail Models of a Forest Using Bounded Quadric Surface Objects

Target Modeling

In order to provide a trainee with the capability for target recognition in a cluttered gaming area, we must represent all potential targets with a reasonable amount of fidelity. This includes friendly as well as enemy vehicles. Modeling such vehicles with edges requires the positioning of many vertices using a physical model or engineering drawings. Quadric surfaces can simplify modeling because they are closely related to the mathematical information used in engineering design. Engineering line drawings are generally produced from cross-sections, or stations, defined along a longitudinal axis. Each station is defined in terms of conic sections, and surfaces between stations are defined by second-order variations in the conic sections. Conic sections are identical to sections of intersection between quadric surfaces and planes, and quadric surfaces have second-order variation. Thus, a modeler can use this information to define quadric surfaces, and the potential exists for automated construction of quadric models using standard engineering design data.

Moving Targets

Modeling a moving target is no different than modeling a stationary scene feature. It must be kept in mind, however, that any model data parameters defining position will have to be changed on-line to reposition the model for each image frame. In edge modeling, all data parameters, including vertex coordinates and surface normals, relate to position. In quadric surface modeling, the shape parameters are not position dependent and therefore need not be changed. In addition, quadric surface modeling produces a much more compact data base than edge modeling, so fewer surfaces will have to be moved. This is particularly important in implementing moving models with moving parts, where multiple transformations of coordinates are involved.

Ground following targets present a particularly difficult problem for real-time CIG. The biggest part of this problem is to determine on which surface a target lies, so that its orientation can be adjusted to fit the surface slope. Quadric surface modeling alleviates this problem because it produces fewer terrain surfaces upon which a target can lie. In addition, structuring the terrain model as a set of individual objects allows the capability of testing all objects in parallel for the presence of a target.

FUTURE EFFORT

We have demonstrated how textured quadric surfaces will solve many scene modeling problems. However, we have only discussed how this approach can be applied to other scene modeling problems. The next task will be to test and refine our solutions to these remaining problems.

The most important problem remaining is to develop techniques to automatically model the DMA elevation data with textured quadric surfaces. To do this we will extend our profile analysis techniques to three dimensions. Next we will extend the scene modeling techniques used in our CNGEN program to place trees and rocks on terrain surfaces other than the ground plane.

We will also develop modeling aids to facilitate the modeling of cultural features, such as targets. We will use these aids to construct a library to be used in conjunction with the DMA cultural file to supplement the terrain elevation data.

It has become clear to us that efficient scene modeling will require the inclusion of two-dimensional feature models. We plan to adapt our basic bounded quadric surface model to two dimensions in the form of linearly-bounded curves. We will then be able to model and image such features as roads, rivers, and lakes more simply.

We will develop st our LOD management techniques, and, final . we will investigate the feasibility of our CNGEN and BLOCK techniques for on-line generation of scene features.

CONCLUSIONS

We have described a new scene model, composed of bounded quadric surfaces and texturing, which simplifies scene generation compared to edge techniques. The new scene model is defined by a parametric data base which is directly related to the size, shape, and position of scene features. In addition, the new scene model produces a much more compact data base because fewer surfaces can be used to model nonlinear features, common in the real world. The effectiveness of the new model is underlined by its capability to model efficiently such irregular features as trees, smoke, and clouds, which are serious stumbling blocks for edge modeling.

ACKNOWLEDGEMENTS

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EXPLODING TECHNIQUES FOR CIG OBJECTS*

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ABSTRACT

This paper will present programming techniques and mathematical algorithms for producing animated sequences of exploding objects such as buildings and ship targets. The visual effect has obvious extension for application in simulation of combat conditions. Potential applications include simulation of weapons effects on real-time CIG visual systems.

*Supported by Navy contract N61339-8-0C-0008
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INTRODUCTION

Computer animation continues to be a valuable tool for the algorithmic generation of time-dependent phenomena. Techniques for the display of motion that have been developed over the past 15 years, combined with display algorithms for high resolution imagery, enables one to generate more realistic pictures and animation. These displays can add to our understanding of complex processes.

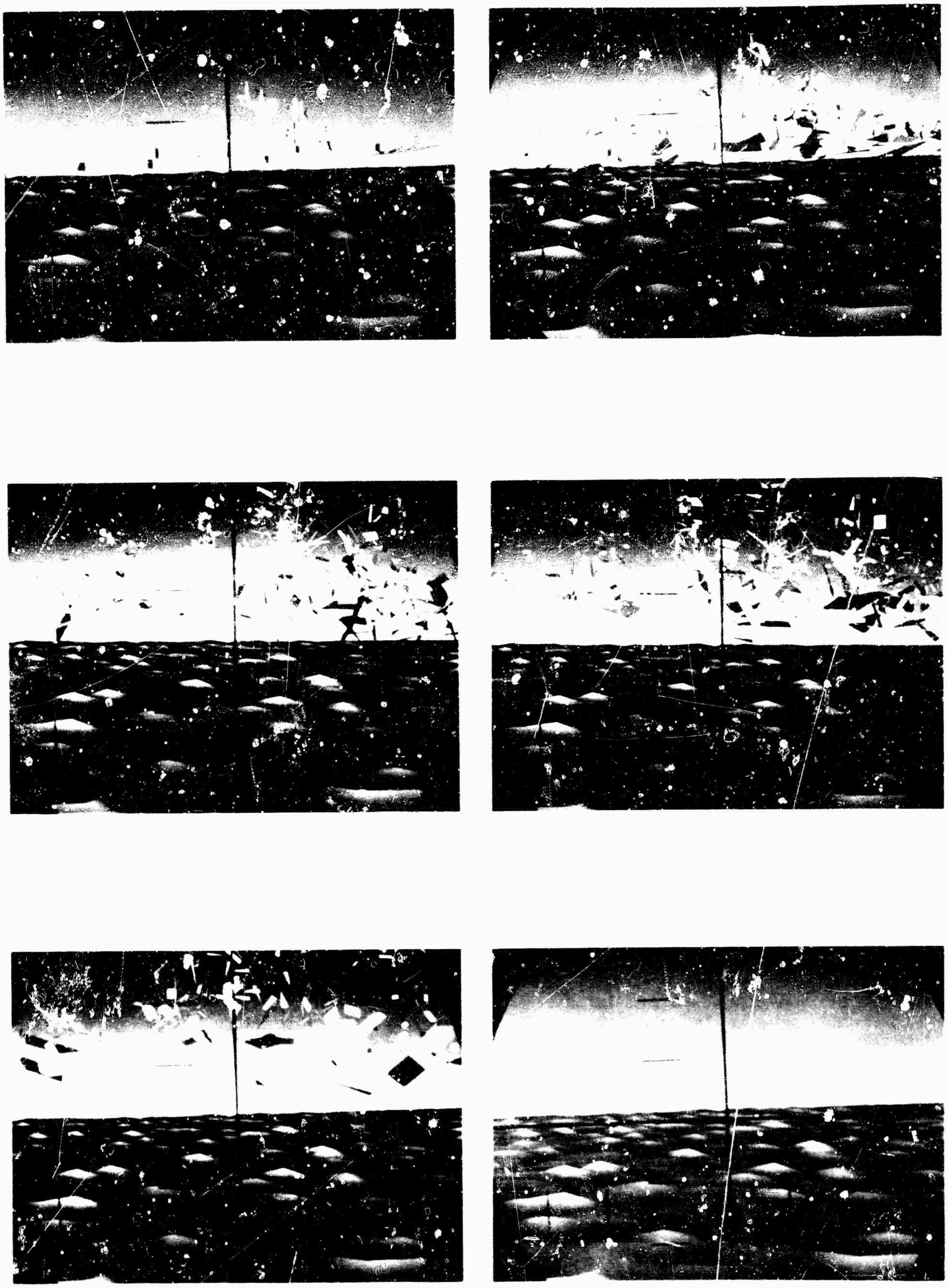
In our research we concentrated on developing tools for highly detailed data base generation. The emphasis has been upon interactive computer graphics techniques to work with a Defense Mapping Agency data base adding cultural features. We also generated at non-real time rates animation which simulated moving along a shoreline of Norfolk, Virginia. During the course of this effort we have considered the requirements for real-time display and the kinds of visual cues one might create to make the simulators more realistic. It occured to us, perhaps serendipidously, that we might be able to simulate explosions because of our data structures and display algorithm.

We have developed a program that we believe has applications for simulators and training. The realism of combat situations portrayed in a simulator with graphics capabilities could be enhanced if, along with maneuvers of the craft or vessels engaged, the destruction of targets were simulated as well. The program takes an object described as three-dimensional data and animates the individual polygons that define its shape. This technique has been used successfully to "explode" and "implode" objects and to alter the shape of objects. For example, the first implementation of the program was the explosion of a realistic model of a tank. It should be noted early in this paper that the goal of this program is not to create lifelike explosions. The explosion of a physical object is an extraordinarily complex phenomenon governed by many factors, including the nature of the explosive and the manner of its detonation, and the properties of the exploding object and its surroundings. These factors affect the size of the blast and the amount of smoke, flame, dust and debris produced. For our purposes we are not interested in faithfully reproducing the processes that constitute such an event. Rather, we wish to produce a visually interesting and unambiguous suggestion of a detonation.

The program is general enough to allow for numerous applications. Buildings, bridges, towers and structures of any kind can be detonated providing simulations for training and education. It can even be used to depict the explosion of a cataract in the simulation of a surgical procedure.

Computer animation deals with manipulation of three-dimensional models. These models are frequently represented as polygonal data. That is, the data is described as a series of coordinate points and a list of polygons that describes the relationships between these points. Traditionally in computer animation, once the object is described there is rarely a need to break it down into sub-parts. During animation, objects are transformed as a single unit to create the illusion of motion. For instance, a three dimensional model of an airplane can be made to fly through space by incrementally translating its position from frame to frame. Objects can be made to grow and shrink by the successive scaling of the coordinate information. These transformations are global, affecting all points and polygons uniformly. The premise of this paper is that since objects are made of component parts (polygons) there exists an inherent ability to manipulate each polygon individually as if they were objects in themselves.

The algorithm to control linear explosions can be explained as follows. The first step is altering the description of the data so that polygons no longer share points with adjoining polygons, as is normally the case. This step increases the number of points in the data description without altering the shape of the object. Next a "movement vector" needs to be calculated for each polygon. This vector determines the direction of travel that a polygon will take during the course of an animation sequence. It is arrived at by subtracting the "center of explosion" from the centroid of each polygon. The "center of explosion" is determined by the animator and is based on the bounding box of the object.



For instance, in the detonation of a tank the "center of explosion" was the minimum height of the bounding box and the center of the object in depth. This "center of explosion" caused the pieces to fly in equal directions in both the horizontal and depth planes, but only upward in the vertical plane, as if the tank was hit dead center by some explosive force.

After the object is redefined into unique polygons and a movement vector is calculated for each polygon the object is ready to be transformed by the main program. The movement that results from this program is based on parameters supplied by the animator. These parameters determine how much and which transformations will occur and their order of occurrence. These parameters consist of a range of minimum and maximum values. They are computed internally by the program using a random number generator. It is our experience that this randomness gives the movement a more natural quality. It is important that the random number generator be given the same seed value for each new frame of animation to insure the movement continuity of each polygon.

Within the main program these steps occur. First, each individual polygon is translated to the origin. Then the rotations (if desired) are performed in the order specified by the animator. The polygons are then translated back to their original position. From this position a new location is calculated based on the polygon's "movement vector" and parameters supplied by the animator. It is at this point that functions such as acceleration and deceleration can be applied. These translations can occur equally in all three coordinate planes or a unique value can be calculated for each of the axes. For instance, if the effect of gravity is being simulated the direction of movement in the vertical plane should be positive at first and then gradually shift to a negative translation until the polygon's position is equal to the level of the ground plane.

A more precise mathematical model of an explosion can be developed into the present program if so desired. The first algorithm represented linear explosions. A second algorithm deals with parabolic explosions. Objects launched in a gravitational field at less than escape velocity will follow a parabolic trajectory. In two dimensions, and without regard to friction, the path of an object along such an arc is given by

$$x = t*v0*\cos(e) \qquad (1)$$

$$y = t*v0*\sin(e) - .5*G*t**2, \qquad (2)$$

where e is the angle of elevation above the x axis, G is the acceleration due to gravity (.98 meters per second), is an initial velocity, and t is a parameter. Since equations (1) and (2) give the position without regard to the previous location of the object, we can extend (1) and (2) to three dimensions by simply specifying an additional angle that gives a direction in addition to the elevation. That is, we can compute x and y in the x y plane, and find the third coordinate by rotating in the x-z plane. This gives

$$x = t*v0*\cos(e)*\cos(a) \qquad (3)$$

$$z = t*v0*\cos(e)*\sin(a), \qquad (4)$$

where a is the azimuth angle, and y is found as in (2) above. This can be expressed conveniently in vector form:

$$x = t*v0x' \qquad (5)$$

$$y = t*v0*y' - .5*G*t**2 \qquad (6)$$

$$z = t*v0*z' \qquad (7)$$

where x', y', and z' are the components of a normalized vector giving an initial direction, v0 is an initial velocity, and t and G are devined as before.

The algorithm for parabolic explosions is analogous to that for the linear case.

```
    for each object begin
       compute the center of explosion CE;

       for each polygon Pi begin
       compute the polygon centroid PCi;
       find the vector Vi from CE to PCi;
       compute v0i, the length of Vi;
       normalize Vi;
       end
end

for each frame
    for each polygon Pi begin
       compute xi, yi, and zi using eqns. (5)-(7)
       compute the change in xi, yi, zi since the
       last frame, call this vector Di;
       translate Pi by Di;
    end
```

While the velocity of the exploding polygons is constant using this algorithm, it is possible to scale this velocity in several ways. We initially assumed that the force of the explosion was constant in all directions. We could however, scale PVi based on say, the distance of the polygon from the centroid, which is just the magnitude of Vi. This would have the effect of giving polygons farther away from the center of explosion small initial velocity. Or we could scale PVi based on some measure of the angle between a polygon, the center of explosion, and some reference axis, and thus give a direction to the blast.

The effect of the algorithm is to translate each polygon along a parabolic trajectory radially outward from the center of the explosion. The center of explosion can be the centroid of the object or some other point chosen to achieve the desired effect. As in the linear case, the algorithm specifies only the position of the polygon and not its orientation, so rotation transformations must be explicitly applied if desired. We can take advantage of the fact that motion in the x-z plane is constant, only the vertical velocity of the object varies with t. Thus we can compute constant x and z increments once, and we need only compute the altitude each frame.

It is a simple matter to calculate when the height of any polygon reaches 0. If the initial height of the polygon is 0, the final value of t, say T, when the polygon again is 0 is given by

T = (2.0 * v0 * y') G. (8)

If the initial height of the polygon is some non-zero value, say h, then we need to increment t beyond the point at which the final height of the polygon reaches zero, since then the object will have returned only to its initial height h above the ground plane. This value of T can be determined from the equation

.5*G*t**2 - v0*y'*t + h = 0, (9)

solving for t with the quadratic formula. Both (8) and (9) give a unique value of T for each polygon, as each polygon will follow a different path depending on its initial direction vector and velocity. Since we can determine the time and position at which the polygon should impact, we can portray a splash, a cloud of dust, or a secondary explosion at the point of impact. Alternatively, we can use the direction and velocity of the polygon during preceding frames to compute a subsequent trajectory and thus cause the polygon to appear to bounce after it struck the ground.

An extension to these programs would be the ability to group polygons into units and then animate these units. Another extension which we implemented creates animation quite unlike explosions and implosions. The idea of manipulating polygons is the same. The difference is that the data structure is not altered into unique polygons. Instead the polygons are triangularized, while still sharing points with neighboring polygons. This step is performed to protect against nonplanar polygons which typical scan coverting algorithms do not accept. With this technique objects can be made irregular and new shapes can be formed. This technique was used to create the ocean like data seen in the accompanying photographs. Before modification this "ocean" was a flat plane. The "waves" were created by random rotation of constituent polygons.

SUMMARY

We have described techniques for the simulation of explosions of crafts or vehicles. In the paper we were not concerned about the precise physics involved in such a problem. Our concern was only with the visual effect. We view this effort as a preliminary effort and more work needs to be done for an implementation in a real-time flight simulator. It is important to mention that much of the realism associated with our explosions is due in part to our display algorithm. Further extensions of our techniques to real-time display would require a careful analysis of the relationships, trade offs and computational costs which may be necessary among various algorithms to achieve realistic explosions.

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CSI, A NEW WAY TO REALISTIC VISUAL SIMULATION

by

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ABSTRACTS

A new fully digital visual simulation principle (computer synthesized imagery CSI) is described that uses digitized image components as terrain, target, sight reticle pattern, and shell tracer. By means of a computer controlled composition unit a sythesis of the components is carried out that leads to a realistic image of the battle field. Outlook is given for further upgrades of the moderate cost principle as well as hints for possible applications.

INTRODUCTION

Visual simulation systems are of outstanding importance for training systems where the enhancement of the trainee s capabilities to assess, and to react to, the information presented to him through his visual perception channel plays a pivoting role.

This, in particular, is obvious for any kind of gunnery simulators for weapon systems with optical sights, flirs, etc. where target aquisition (detection, recognition, identification) is a significant phase of a full engagement.

At first the most important requirements for a visual simulation system for any kind of gunnery shall be discussed.

The first set of requirements refer to the presentation of the terrain image and is given in table 1.

The next set of requirements is collected in table 2 and describes the target presentation in this terrain image.

Finally a set of requirements as given in table 3 depicts the influence of the weapon system under consideration on the visual simulation system.

Looking at these tables the most critical areas can be determined that existing visual simulation principles are suffering from either individually or in combination. These areas are given in table 4.

COMPUTER SYNTHESIZED IMAGERY PRINCIPLES

In the past two years Honeywell has tried to find answers to the questions raised in the preceeding chapter with the development of the fully digital CSI (computer synthesized imagery) principle.

The following paragraphs shall give an introduction into the principles of operation of the CSI.

As one can take from the name the basic idea of CSI is to synthesize the image which shall be seen by the trainee from the typical image components as given in table 5.

The following basic block diagram in figure 1 shall give an introduction into the principle of the system.

This block diagram shows four memories. In the first memory, a digital image of the terrain is stored. A second memory allows for storage of all images of one or more targets. A third memory contains the pertinent sight reticle pattern of the weapon system under consideration, and finally a fourth memory contains the weapon delivery effects as tracer, burst on target, etc.

Each of these memories delivers a digital image information to a digital composition unit which is under control of a process control computer.

In this unit, the afore mentioned synthesis of the images is carried out. It results in a digital TV image with a size of 600 by 600 pixels each with four to six bits. Provided this image is read out, and converted into, a video according to the television standards (i.e. with the corresponding frame rate), a standard TV image can be displayed on the screen of a television monitor.

TECHNICAL SOLUTIONS

After these more general remarks some detailed explanations shall be given.

Terrain Memory

First the terrain memory and the digital terrain image will be discussed in more detail.

Basis of the digital terrain image is a panorama foto taken by a 360 degrees azimuth camera at any desired location in the real world. This foto representing a cylinder projection of the actual terrain is submitted to a standard digitization process, the result of which is a digital terrain image that can be stored in a computer mass memory, preferably a magnetic disk. If necessary, image editing can be carried out to erase scratches on the film, to compensate for film exposure discrepancies along the 360 degrees azimuth, misalignments of the film on the digitizer, and other.

Because of the limited reading speed of the disk, the whole digital terrain image is now read into a high speed random access memory. From here, the image is now delivered to the digital composition unit as shown in figure 1.

This process shall be explained in more details in figure 2.

This figure shows that in a preparation phase the random access memory is loaded with the terrain image.

Now, according to the viewing direction of the trainee and the field of view of his optic, the corresponding image section is addressed via the process control computer, and lifted out of the random access memory. After digital to video conversion, it can now be displayed on the TV screen.

It is obvious, that, to obtain standard TV frames, the whole transfer from the random access memory to the TV screen must be under the control of a TV clock that runs the process according to the TV standards. This means, that the random access memory must deliver a pixel stream with a rate of about 60 nanoseconds per pixel. That means also, that within each frame time a new image is to be generated, and transmitted to the screen. By means of the signals derived from the control handles of the trainee which define the section to be displayed on the screen, a continual motion of the image can be achieved.

Furtheron, a special techique allows for simultaneous read out of more than one image, even when an overlap of the images occurs. This, in turn, allows for sharing the high speed random access memory for a larger number of trainees, which gives an optimal memory utilization.

To obtain best resolution, the TV screen diameter is matched to the field of view of the optic under consideration. This in connection to the azimuth and elevation gaming area determines the total size of the memory. Because of the multiple access capability, however, only one memory for several users is to be made available.

Target Memory

Next, the target memory shall be discussed.

Generally, the target image can be generated by the well known CGI process. This can be either a real time process, that requires all pertinent special purpose hardware and real time software, or a non real time process. In the latter case, all target perspective views that make up a complete target trajectory of a moving target, are generated and stored in the target memory as shown in figure 3 together with a set of addresses that determines at which area of the terrain the target shall appear.

These views, now interpreted as consecutive frames, are read from the memory into the composition unit with a standard TV frame rate. That means, that alike the terrain memory, the target memory delivers a pixel stream the timing of which is identical to that of the high speed random access memory for the terrain.

Regarding the size of the memory, the following consideration can be made.

Only in some more unrealistic constellations, the target would have the full size of the field of view. However, taking realistic engagement ranges and target sizes into consideration, it can easily be determined, that the target size in relation to the field of view rarely exceeds 10 % of the field of view. Thus, with the field of view being represented by 600 vertical TV lines, a target would be represented by about 60 lines at maximum.

This, in turn, leads to a practical target memory size of 64 by 64 pixels per target frame. While for the terrain a pixel size of 6 bits turns out to be most adequate, a target pixel size of 4 bits is fully satisfactory.

Sight Reticle Pattern Memory

It appears more practical to generate a reticle pattern on the TV screen rather than to use an optical reticle in front of the screen. Thus any mechanical adjustment can be avoided.
In comparison to the terrain and target memory, the sight reticle memory is fairly simple. Its size is 600 by 600 pixels with only one bit per pixel. Such a memory can be loaded with any kind of sight reticle pattern.

Because some sights have variable reticle parts, as for instance the turret position indicator of a tank sight, two memory planes are used which can be shifted with respect to one each other as shown in figure 4.

Tracer Memory

The tracer memory also is a simple memory. It contains only one pixel per round with 4 bit for each pixel to allow for brightness variation in accordance with the increasing distance to the observer.

The addresses of the tracer pixel are calculated in the process control computer according to the shell trajectory and the parallax angle.

Burst on Target Memory

The burst on target memory has a size of e.g. 3 by 3 pixels with each one bit. The address of the center pixel is identical to that of the tracer pixel. The burst on target memory, however, is only activated if a hit occurs, and than only for one or two frames. Thus, a short flash on the target can be made visible.

Image Composition Unit

The preceeding paragraphs described, that each image component is delivered as a pixel stream from its memory. The composition process, now, is controlled by two main parameters which are addresses and priorities.

This shall be demonstrated by means of the most complex composition process for terrain and targets.

First, the position of the target in the terrain can be easily determined by a set of addresses of consecutive target frames in reference to the terrain addresses. This process is depicted in figure 5. Whenever the terrain addresses reach the addresses of the target, the composition unit is armed to switch to the pixel stream of the target memory. The switching finally is carried out when a target pixel occurs that deviates from zero.

Second, the priority control shall be investigated.

To achieve high realism, a target must either appear before a terrain feature as for instance a bush, when it is closer to this, or behind a terrain feature, when it is further away. In terms of priority, this means that either the target pixels have higher priority than the terrain pixels (thus the target obscures the terrain behind), or the terrain pixels have higher priority which results in a partial or a full masking of the target by the terrain feature.

Now, with a given target trajectory in the terrain, it is fairly easy for an observer to visually determine those features which may obscure the target. This features are marked on the screen in a preparatory process as so called obscuration lines as shown in figure 6. This process, in turn, generates a set of priority bits that is associated to the addresses of the terrain pixels, and that finally controls whether a terrain or a target pixel is to be displayed.

As the degree of detail of the the obscuration lines goes down to the pixel level, the addresses of the target obscuration can be obtained to the same degree. This, for instance, allows even for a target being partially visible through the branches of trees.

Similar processes, as described in the preceeding paragraphs, finally are used to determine the visibility of the reticle sight pattern and the tracer.

Special Effects

Look up table techniques are used to

allow for following effects:

- daylight conditions
- visibility (fog/haze)
- gun smoke

Likewise, in connection with some more complex transfer functions, look up tables even allow for the simulation of the thermal image.

OUTLOOK

In the preceeding paragraphs, the present status of the CSI visual simulation system capabilities is described. Beyond that, the following enhancements can be integrated into the excisting design.

Color

Being based on the TV principle the black and white CSI system can be upgraded to a color system by means of adequate memory space. This in principle does not affect the composition process.

Battle Field Smoke

In a similar way as targets, smoke columns can be planted into the terrain with variable ascent angle being determined by a wind velocity datum.

Terrain Impact

Dust clouds at a terrain impact of a shell can be planted into the image again by means of similar techniques, while time controlled look up tables provide the typical fade away.

Target Dust Clouds

Dust clouds appearing behind moving targets finally can be generated also in a similar way as those at the impact point of the shell.

User Designed Target Trajectories and Scenarios

It appears highly desirable that the user of a training system, i.e. the instructor, has means to create target trajectories and scenarios in accordance with the given training doctrines. Provided a sufficient target data base is stored on the system disk this important feature can be made available by means of an extra software package. This package will allow the instructor to plant a target at any desired spot into the terrain and match its size and orientation to the given terrain conditions at the selected spot. By means of interpolation routines, a sequence of such targets can be converted by the system computer into consecutive target frames thus resulting in a new moving target trajectory.

CONCLUSION

The CSI visual simulation principle as described in the preceeding paragraphs seems to be a useful contribution to the family of existing visual simulation systems. With its fully digital process it avoids any mechanical component and allows for the application in rough environment.

For most of the processes being software controlled the reproduction of a CSI system ranges in a moderate price level.

Finally with its realistic images, CSI seems to be an ideal visual simulation for any kind of weapon systems ranging from tanks over anti aircraft guns, missile launchers to hand held weapons as bazookas, wire guided anti tank missiles or comparable.

ABOUT THE AUTHOR

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TABLE 1

REQUIRIREMENTS FOR TERRAIN IMAGE

TERRAIN IMAGE

- O MUST BE REALISTIC
- O MUST BE ARBITRARY
- O MUST BE EASILY EXCHANGEABLE
- O MUST HAVE WIDE GAMING AREA
- O MUST HAVE VARIABLE LIGHTING CONDITIONS
- O MUST HAVE COLOR
- O MUST HAVE BATTLEFIELD SMOKE

TABLE 2

REQUIREMENTS FOR TARGET IMAGE

- O TARGETS MUST BE REALISTIC
- O TARGETS MUST MOVE REALISTICALLY
- O TARGETS MUST HAVE REALISTIC MASKING
- O TARGETS OF ANY KIND MUST BE AVAILABLE
- O TARGETS MUST APPEAR IN GROUPS
- O TARGET SCENARIOS MUST BE USER DESIGNED
- O TARGETS MUST GENERATE DUSTCLOUDS
- O TARGETS MUST GENERATE MUZZLE FLASHES

TABLE 3

GENERAL VISUAL SIMULATION REQUIREMENTS

VISUAL SIMULATION MUST ALLOW FOR

- O SIMULATION OF FLIR
- O VARIABLE SIGHT MAGNIFICATIONS
- O IMAGE AS SEEN WITH NAKED EYE
- O SIMULATION OF WEAPON
  - GUN SMOKE
  - SHELL TRACER
  - TERRAIN IMPACT
  - BURST ON TARGET
  - RICOCHET

TABLE 4

DEFICIENCIES OF

EXISTING VISUAL SIMULATION PRINCIPLES

- O UNREALISTIC TERRAIN IMAGE
- O EXPENSIVE TERRAIN DATA BASE
- O LIMITED GAMING AREA
- O UNREALISTIC TARGETS
- O UNREALISTIC TARGET MASKING
- O NO USER DESIGNED TARGET SCENARIOS

TABLE 5

COMPONENTS FOR CSI VISUAL SIMULATION

O TERRAIN IMAGE	: TABLE 1
O TARGET IMAGE	: TABLE 2
O SIGHT RETICLE PATTERN	: TABLE 3
O WEAPON DELIVERY EFFECTS:	TABLE 4

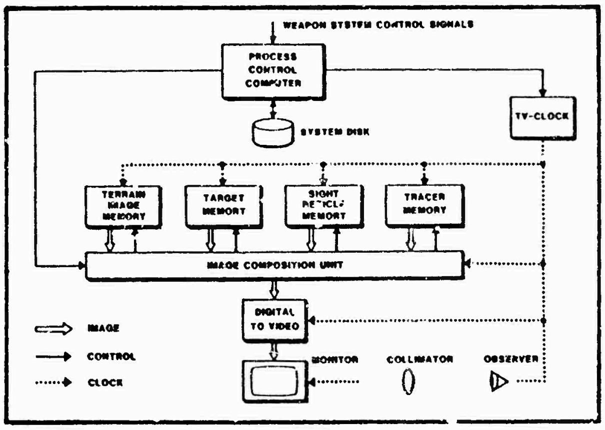

FIG.1 : BASIC BLOCKDIAGRAM FOR CSI SYSTEM

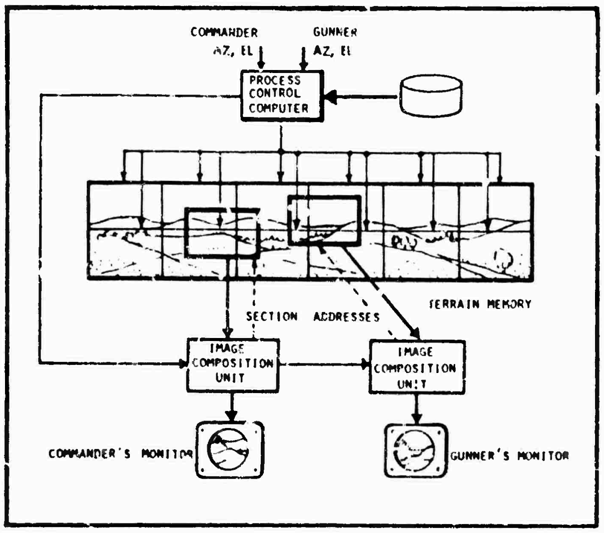

FIG.2 : TERRAIN MEMORY

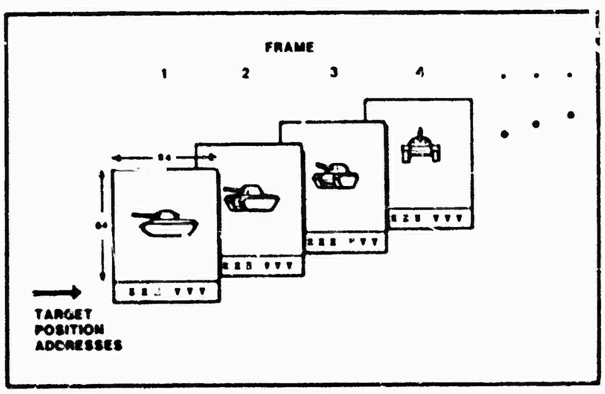

FIG.3 : TARGET MEMORY

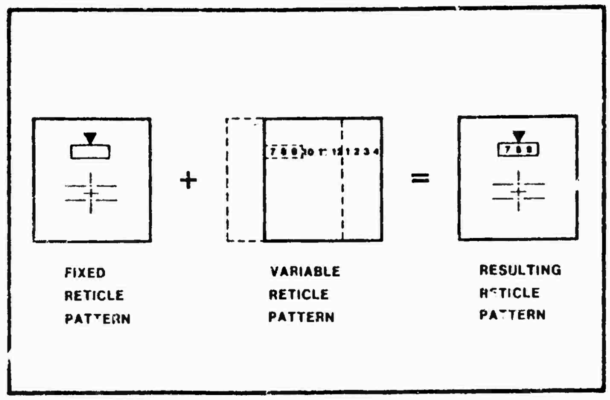

FIG.4 : SIGHT RETICLE MEMORY

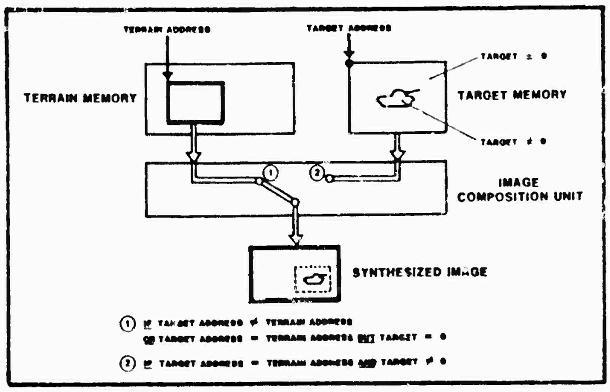

FIG.5 : IMAGE COMPOSITION UNIT

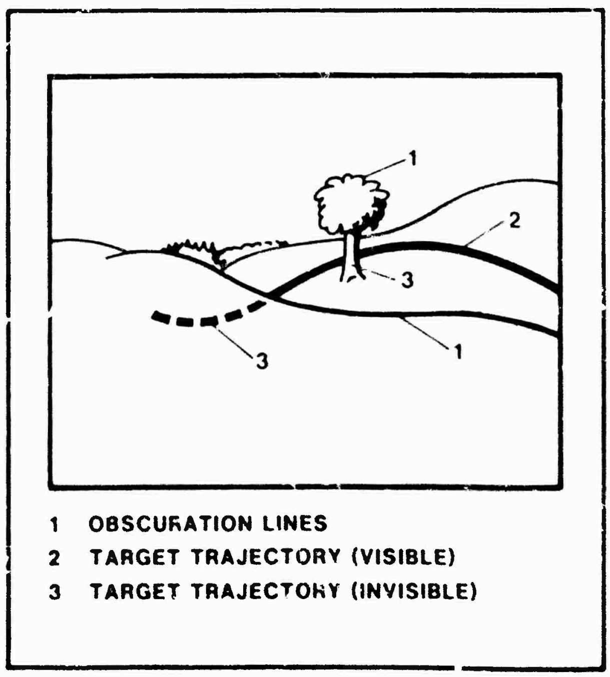

FIG.6 : OBSCURATION LINES

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GROUND FORCES TRAINING DEVICES AND TECHNIQUES: WARSAW PACT COUNTRIES

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ABSTRACT

This paper reviews recently developed training devices and techniques used by the Warsaw Pact countries (WPC) to improve the combat readiness and effectiveness of their ground forces. Most of these devices are relatively simple, straightforward, and tailored to the tactical doctrine of the Warsaw Pact forces; however, Soviet literature has recently mentioned the use of laser simulation equipment as a training device for gunnery training. The use of mockups and of special simulation equipment and techniques is emphasized, particularly in tank-gunnery, chemical-biological-radiological, and air-mobile-troop training.

INTRODUCTION

The high performance and destructive power of modern weapons and equipment necessitate that operators be able to respond rapidly, aim with extreme accuracy, and have a thorough knowledge of the effectiveness and operational limits of combat systems. To achieve these results, military leaders of the WPC believe that the best training consists of repetitive functions under varying conditions, with a gradual increase in the degree of difficulty. This procedure best familiarizes the trainees with the weapons or equipment, ensuring maximum effectiveness in their use. As their unit commanders seek more efficient methods of preparing troops for combat operations, simulation techniques and devices receive more attention. The increase in the variety of teaching aids, mockups of actual equipment, miniature training grounds, and innovative methods and techniques is certainly intended to provide for a higher quality of training. In classrooms and demonstration exercises, instructors use mockup posters, diagrams, films, and slides. Simulators and mockups are used when the trainees are considered proficient in the basic techniques. Many training areas contain small terrain mockups equipped with miniature terrain features, manmade structures, and equipment for use by the trainees to further their training in practical problems.

The training programs of the non-Soviet WPC ground forces are essentially identical with that of the Soviets. They differ primarily in standards of qualification and in the types of training aids and simulators. The types of training devices developed for use by the various branches of service vary from complex sophisticated simulation equipment to locally fabricated simple training aids.

DISCUSSION

Tank Training Simulation

Extensive training is conducted on simulators during tank gunnery training before trainees actually operate the tanks or fire the main and secondary armament on standard ranges. Unit commanders are allowed a wide latitude in selecting and developing training aids. Among the devices used in training tank crews are gun trainers to improve sighting and aiming skills; trainers with sights, instrument panels, and instructor's control panels; and tank trainers on motion simulator platforms to simulate cross-country movement. Newer Soviet tanks have elaborate training simulators. For the gunner a cutaway turret (fig 1) includes the fire control and automatic loader. A trainer consisting of a hull on which a turret is mounted (fig 2) is used to train the tank crews in methods of conducting fire against fixed, disappearing, and moving targets during the day and at night. The turret includes a mockup of a tank gun, a stabilizer, a training machinegun, a gunner's night sight, a commander's periscope, and a tank intercom system. The tank rocking frame device consists of a metal frame onto which a tank may be placed and rocked to simulate cross-country movements. It is used in conjunction with sighting and gun-stabilization devices. The frames are usually installed in classrooms, cantonment areas, and subcaliber ranges.

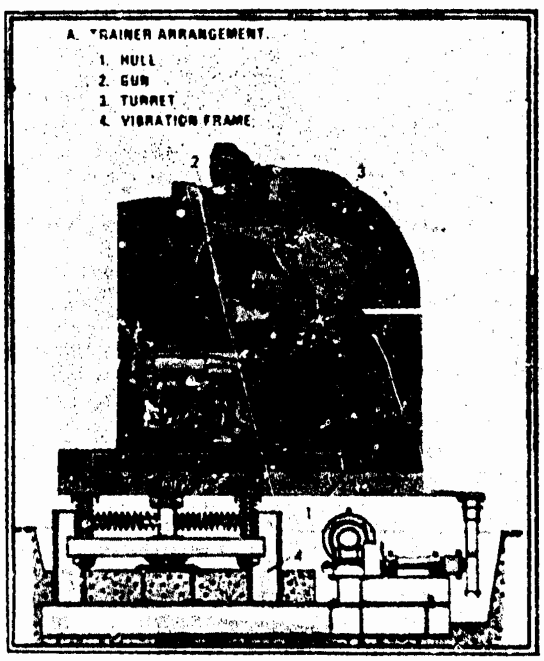


Figure 1. Training Turret

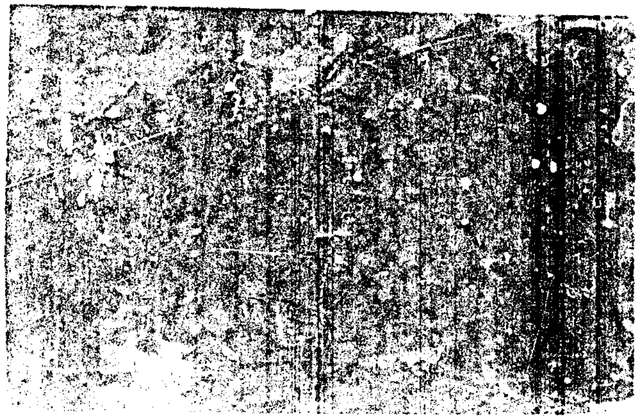


Figure 2. T-72 Tank Trainer With Automatic Loader

Numerous training aids have also been developed for tank drivers. These trainers range from a simple device for teaching the rules of the road to an elaborate driving simulator that provides the trainee with a duplicate of the actual driver's compartment, which pitches and rolls to match the terrain projected on a screen in front of the trainer. These elaborate simulators also create engine noises that result from the trainee's use of the gear selector and his manipulation of the accelerator.

An Artillery Weapon Simulator

The military forces of the WPC consider the multiple rocket launcher (MRL) a principal artillery weapon, and each crew member must be trained to know its capabilities and performance characteristics. During specialized training, the classrooms in which the training is performed are divided into two sections, one for theoretical study and the other for practical exercises. Theory is taught in a classroom equipped with training aids, including the latest models of audio and visual devices, recorders, and projection equipment. Practical training is conducted on a mockup weapon installed on a special frame that provides the students with full-circle accessibility. All of the control and functional elements are exactly like those of the actual weapon. A training mockup of the Czechoslovak M-70 MRL is shown in figure 3. The students are taught start-up, operating, and shut-down procedures that they will perform on the weapon. All electrical- and hydraulic-powered elevating, traversing, and reloading components and controls are accessible for maintenance, repair, and adjustment through removable plexiglass covers. During the instruction periods, malfunctions in the weapon are purposely introduced, and students are required to locate and eliminate the mechanical source of the problem until the system is operating properly. The MRL simulator is considered to be an important development for providing realistic progressive training for the crew in the operation of the weapon system.

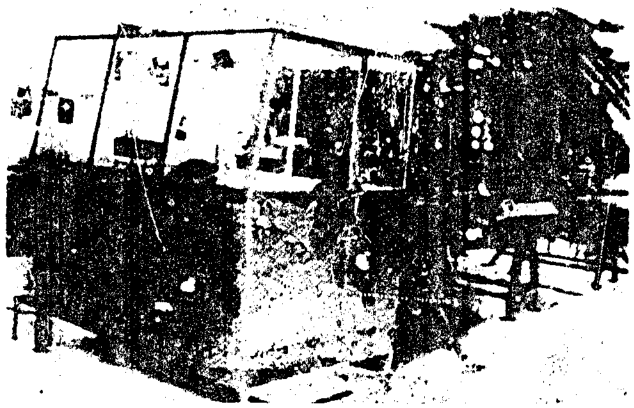
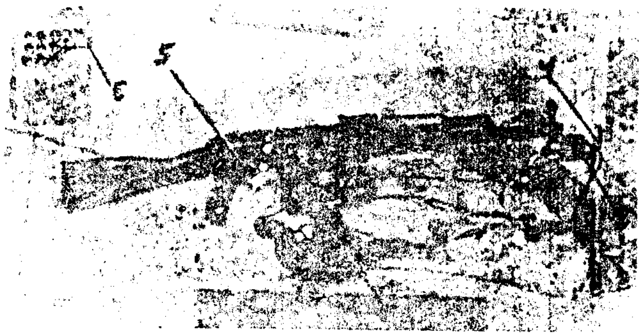


Figure 3. Czechoslovak MRL Training Simulator

Rifle Training With Simulators

The WPC small-arms training methodology has remained basically unchanged since World War II. Their military forces have been able to produce effective infantrymen ready for combat because of their effective rifle training, which closely resembles combat conditions. Training scenarios simulate the manner in which the ground forces plan to employ small arms in combat. Although basic methodology has not changed, the WPC emphasize new training techniques, hardware, and devices in an effort to produce superior riflemen who are ready for combat. They have developed devices such as aiming devices, and optical devices to be used in rifle training programs. BMP armored vehicle gunnery training is emphasized, and a trainer for BMP personnel is available. Several electro-optical devices that use laser or light beams to simulate bullets have been developed for use in this training. In most of the items, photocells are installed on the target to register a "hit." The primary advantages of these devices are that they are completely safe, relatively inexpensive to produce, and take up little space. Some are designed for classroom use, others for ranges.

The electric aiming device (fig 4) was invented by a soldier in a Soviet military unit and is used by that unit; such innovations are encouraged. The device uses electro-mechanical equipment in conjunction with an aiming stand, which is free to rotate both vertically and horizontally. The trainee's rifle is fastened to the base, a solenoid sensor is attached to the muzzle, and a wire is attached to the trigger. An instructor performs the initial alignment; then, the rifle is turned off target. When the trainee aims and then "fires," the weapon is fixed in place. If the shot is accurate, the checking light on the range officer's panel is not illuminated. In case of a miss, however, the lamps light; the deviation is used to judge the aiming error.



1. Regular-issue stand
2. Aluminum screen
3. Solenoid sensor
4. Miniature target
5. Electric trigger
6. Range officer's panel

Figure 4. Electronic Aiming Device

Programs to teach infantrymen the necessary skills to engage aerial targets are incorporated into the rifle training program. Soviet writings indicate that there are distinct stages of progression in teaching troops to operate against aerial targets, and mockups have been established at various ranges to simulate these actions. Advanced training for air-mobile troops involves firing at ground targets from inside helicopters. Mockups provided at air-mobile training ranges are used to familiarize trainees with helicopters and to provide practical experience in firing on aerial targets.

An Antiaircraft Missile Simulator

Relatively simple in design and operation, this antiaircraft missile simulator (fig 5) was developed to train operators in the firing of a portable antiaircraft missile equipped with an infrared passive guidance system and intended for use against low-flying enemy aircraft. The simulation equipment is mounted on the actual weapon, allowing the operator to make use of the normal weapon system controls while carrying out simulated practice firing continuously. During a simulated firing operation an aircraft target generated by the simulator image projector enables the operator looking through this aiming sight to see the target projected on a screen. Visual and audio signals transmitted at the instant of firing indicate that the target has been "locked on" and the operator needs only to release the trigger mechanism to fire a simulated missile for a hit or miss. During the course of instruction the proper procedures for firing are supervised by an instructor standing by. Instrument readouts at the moment of launch provide the instructor with results for scoring and evaluating the progress of the trainee-operator.

Figure 5. Simulator for Soviet Antiaircraft Missile System

Combat Engineer Trainers

Combat engineer training emphasizes the use of simulation equipment. Two recently described operator trainers simulating the BAT/M dozer and the MDK-2 ditching machine (fig 6 and 7) have been developed by the Soviets. The dozer is used primarily as a route clearer and consists of a hydraulically operated dozer blade mounted on the front of the AT-T heavy tracked artillery tractor. The dozer trainee has a trainee's seat equipped with simulated crane hand controls, working elements, and a dozer blade. Included in the equipment are an error-display panel and an instructor's panel with indicators and controls for monitoring the exercise. The MDK-2M ditching machine can entrench command posts, troops, guns, tanks, vehicles, and equipment. Its trainer has a simulated dozer blade and trenching components, a trainee's seat, and an error-display panel. The engineer equipment trainers are prime examples of the Soviet use of simulation technology. Much of the extensive training required of the operators can be conducted in a controlled learning environment with simulated practice. While the use of these trainers does not eliminate the use of actual equipment, the Soviets claim that the training period on the engineer equipment itself is reduced by as much as 25%. This reduction although fairly modest, would help to extend the service life of the equipment, decrease training time, and provide cost savings in fuel and maintenance so that, in turn, the resulting savings in military training costs would be significant.

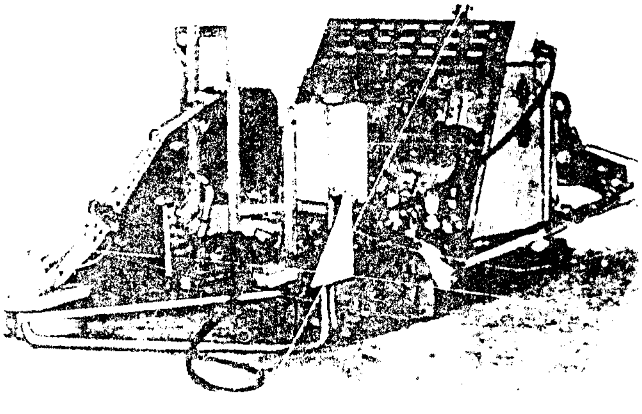


Figure 6. Soviet BAT/M-T Trainer

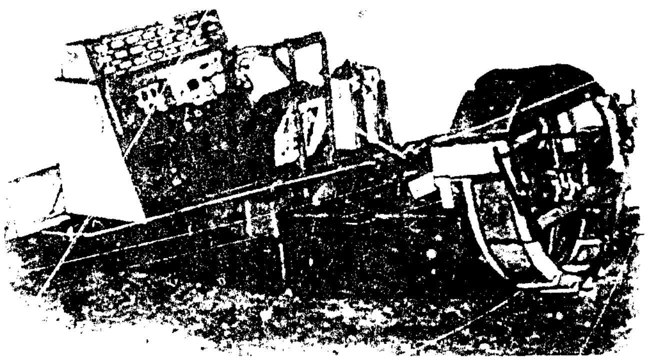


Figure 7. Soviet MDK-2-T Ditching Machine Trainer

Chemical, Biological, and Radiological (CBR) Warfare Training Devices

In their effort to prepare chemical units to operate effectively in an environment contaminated by CBR agents, the WPC military leaders have encouraged the use of training devices and special simulation techniques. The ability of their troops to operate effectively in a CBR-contaminated environment is of great concern, and troop proficiency in reconnaissance, detection, and decontamination operations is strongly emphasized. Part of this training is given in the classroom and is supplemented with training aids and devices. Films, slides, and electronic aids are also useful in demonstrating techniques. CBR training seems to be concerned primarily with chemical and nuclear warfare. Several devices containing simulant agents (to contaminate terrain and materiel for use in training) have been described and discussed in Soviet publications. To simulate chemical contamination for training purposes, the Soviets occasionally use a detector training device that contains tubes for identifying various CW agents. Hydrogen cyanide and mustard tubes have been mentioned, and liquid ammonia is frequently used as a CW agent simulant. Training devices are frequently used to simulate a nuclear explosion. A device described as a mushroom-cloud simulator is usually associated with a grid to simulate radiation fallout patterns. The device simulates the ascent of the cloud from near ground level after a nuclear explosion. With the aid of the simulator the trainee is able to practice making the measurements necessary to determine the yield of the nuclear weapon. To facilitate classroom teaching, the Soviets have developed a laboratory device that provides practical training in the use of the chemical detector kit.

To supplement the training of decontamination specialists on the actual TMS-65 decontamination vehicle, the Soviets developed a TMS-65 trainer (fig 8). The trainer is designed to meet the special requirements of simulated training, emphasizing only those agents considered significant and enabling the instructor to supervise the trainees with maximum efficiency. Complete simulation of the controls and the realistic turbojet engine would give the trainee the impression that he is operating actual equipment. After completing the required instruction, a trainee would then advance to become proficient on the actual TMS-65 system.

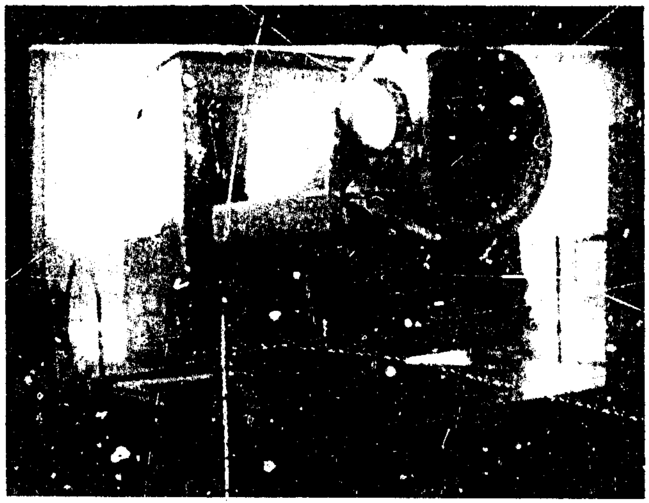


Figure 8. TMS-65 Decontamination Vehicle Trainer

Electronic Systems and Simulation

To enhance the effectiveness of training in an electronic warfare environment, WPC commanders give considerable attention to training with the aid of simulation equipment. Radar simulators have been available for almost as long as the radars themselves. Reportedly under development is a system that uses digital computers to improve the radar operator's training skills. A radar classroom which is an exact replica of the inside of a radar station has been reported. It is said to have simulation equipment that allows situations closely resembling real combat to be displayed on the indicator screens. The importance of acquiring skills in handling simulators and trainers to meet the requirements of effective combat training has been emphasized.

CONCLUSIONS

Training devices are playing an increasingly important role in the efforts of the WPC ground forces to successfully achieve their training objectives of combat readiness. Their efforts to improve and provide higher-quality training through the use of simulation technology and training devices are well known. The role of the training device as an essential tool for repetitive training under realistic combat conditions is becoming increasingly important to the WPC military leaders. As new and more sophisticated technology is introduced into combat equipment, training requirements become more intense and complex. These events lead to the introduction of new types of simulators and training devices

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AD P000161

MACE/MICRO-DISC: A MICROCOMPUTER - VIDEODISC BATTLE SIMULATION SYSTEM

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ABSTRACT

A new, effective, and low-cost battalion(BN)-level battle simulation system, the MACE/Micro-Disc System, has been developed, under the sponsorship of the US Army Combined Arms Training Development Activity (CATRADA) at Ft. Leavenworth, Kansas. The MACE simulation is an improved version of the Army's Computer Assisted Map Maneuver Simulation I (CAMMS-I), modified to operate on a low cost personal microcomputer-videodisc (Micro-Disc) system. Map boards are replaced with military maps stored on a videodisc and displayed on color monitors. Unit location, status and action are shown in a graphical map overlay generated by the microcomputers. Operators/analysts can examine the simulated battle situation by scrolling the map using a joystick. The overlay is keyed to map coordinates and scrolls with it. In addition, the operator can zoom to focus on a selected area. The areas displayed can range from 4 to 40 km on a side. The Micro-Disc System employs distributed processing supported by multiple personal microcomputers and video-disc players sharing a common hard disk mass storage unit. This distributed processing architecture and local area networking permits graceful degradation in the event of failure of one of the microcomputers; an exercise can continue to function with other microcomputers in the system performing the functions of the disabled microcomputer. Local area networking also permits easy expansion of the system for more complex simulations. Operational tests of the system by the 9th Infantry Division at Ft. Lewis, Washington have produced results exceeding expectations.

BATTALION-LEVEL COMMAND AND CONTROL TRAINING

Current Approaches

Rapidly evolving microcomputer, distributed processing, and videodisc technologies have been integrated into an effective, efficient and low-cost battalion (BN)-level command and control (C^2) training system--the MACE/Micro-Disc System. This system can meet critical Army needs in BN-level C^2 training.

BN-level training in the US Army currently is limited to one or two CPXs per year, typically manual. Selected CONUS units travel to Ft. Leavenworth, Kansas, once every three or four years to use the Combined Arms Tactical Training System (CATTS). There is some use of board games, and some use of the Computer Assisted Map Maneuver Simulation I (CAMMS-I). While each of these approaches can provide valuable training, their limited use can be attributed to specific shortcomings:

(1) Manual CPXs are people-intensive, requiring a sizeable staff of controllers to produce a realistic exercise. Battle outcomes are decided by the subjective judgment of the controllers.

(2) Board games are also people-intensive, and are vulnerable to dominant personalities among the players. There is again no objective source of resolution of scenario conflicts.

(3) CAMMS is objective, effective, and available, but still uses map boards and does not work in real time. In addition it must be operated via a dial-up telephone circuit to Minneapolis, and other locations. This is expensive and difficult to schedule.

(4) Except at CATTS, a realistic, stress-filled environment is difficult to maintain. The fidelity of the TOC setting, and of the interaction of the BN comander and his staff with the BN elements playing the scenario are essential to effective training.

(5) CATTS training is effective and realistic, but expensive because of the travel, and has insufficient availability to meet training needs.

With the training system located on-site, BN staff training programs can be expanded. It will be easier to schedule training sessions, and easier to reschedule if BN plans have to change for any reason. In addition, new training capabilities can be developed which use the MACE/Micro-Disc System and are tailored to local needs. These advantages are gained at low cost.

The C² Training Requirement

BN readiness requires that C² training exercise the functions performed by the BN commander and his staff in a realistic stressing environment. Emphasis must be placed on command decisions, control from brigade (BDE) through BN staff to companies and other BN support elements, coordination among BN elements, information management and use, and the use of BN assets.

Exercising C² functions does not require fully detailed tactical resolution (e.g., line of sight determination for individual weapon systems). It does require accurate replication of the flow of information on the battle situation and the interaction between the BN commander, his staff, BDE headquarters, and BN elements. The simulated sequence of events in the battle external to BN headquarters must be consistent with a realistic scenario.

C² in battle is highly stressing. Therefore, a training simulator must stimulate the players both physically and mentally. On the physical level, the play area must look and sound like a tactical command post near the front. From the mental perspective, the effects of orders, and the results of conflicts between friendly forces and the OPFOR must be both objectively determined and perceived as objective. This requirement calls for a computer-driven simulation that can quickly determine the results of complex battle situations based on the relative strengths of units and their weapons.

Finally, local operation of the simulation is needed to assure easy and frequent access by individual BNs. Each BN should train several times a year. Local control makes this possible and simplifies rescheduling when it is needed.

THE BATTLE SIMULATION CENTER CONCEPT

C² training requirements can be met by the Battle Simulation Center (BSC). The essential feature of the BSC (Figure 1) is that it places the BN commander and his staff in a situation that closely simulates actual stress-filled battle conditions. The commander and his staff operate out of M577 mockups or actual command post vehicles. A jump TOC, real or simulated, is also provided for use as needed to be consistent with the situation in the battle simulation (Figure 2).

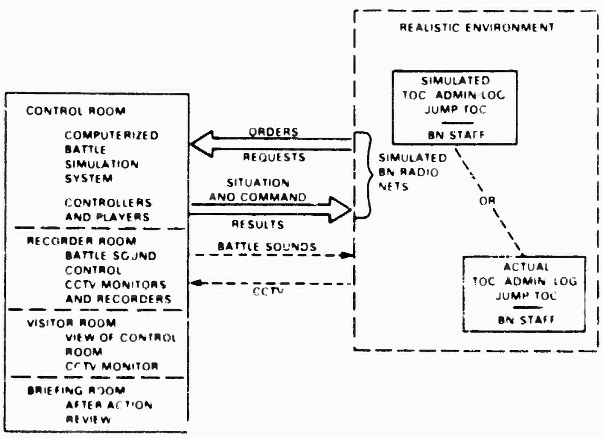

Figure 1. The Major Elements of the BSC.

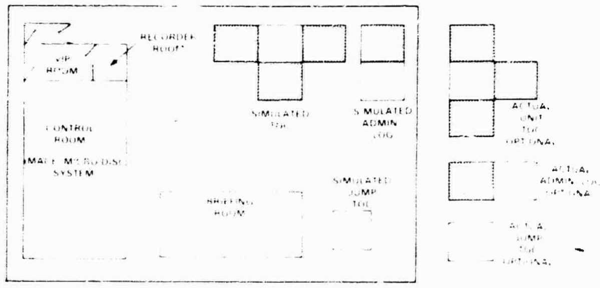

Figure 2. Representative Layout of the Battle Simulation Center.

All operational BN radio nets are simulated, including the play of electronic countermeasures (ECM). The command and staff receive all inputs and issue orders on the simulated nets. As far as the commander and his staff are concerned, the interaction on the radio nets and the type of information exchanged are the same as would be found in an actual battle.

The BN commander and staff do not see that the company commanders, BDE staff and fires/air personnel are working at computer stations in the control room. Orders from the BN commander are interpreted by the company commanders much as they would be in the field, and entered into the computer. The battle simulation system moves units and determines the outcomes of conflicts. The results are displayed on the monitors, and reported to the BN commander and staff. Similarly, fires/air, admin/log and BDE HQ are played as they would be in the field.

The BN actions are countered by OPFOR players who are free to act on their own, consistent with the doctrine of the enemy forces. OPFOR units in the simulation can thus counter BN actions, and attempt to take advantage of any opportunities offered by BN player actions.

Battle sounds, ranging from small arms fire to artillery, are provided and represent an important part of the realistic environment. The type of sound, level, and direction are all controlled from a recorder room to reflect the battle situation.

Observation of player activities for exercise control and eventual player feedback is provided by a closed-circuit TV (CCTV) system to maintain a realistic environment. Scenes from the TOC, admin/log and jump TOC are monitored and recorded in the recorder room. Provision is made for visitors to observe control room activities and view CCTV scenes of TOC activities from a separate visitor room. A briefing room is also provided to conduct after-action reviews. All the controllers, players, the BN commander and staff participate.

The BSC concept has been proven effective in years of operating CATTS and CAMMS, and in the operational tests of MACE. The US Army has successfully applied the concept to training BN commanders and their staffs for eight years in the CATTS operation at Ft. Leavenworth. The more recent CAMMS system has less resolution than CATTS, but has shown that computer-assisted BN level C^2 training can be successfully conducted on-site via phone links to a large central computer. The MACE BSC more closely resembles CATTS in terms of fidelity to an actual battle situation. The MACE simulation is an upgrade of the CAMMS software, redesigned to fit a low cost microcomputer network that is readily implemented on-site.

THE MACE/MICRO-DISC SYSTEM

MACE--an Improved Version of CAMMS

MACE uses the conflict algorithms and combat resolution data from CAMMS reorganized to operate on a distributed network of personal microcomputers. Videodiscs were added to the system to store and display standard military maps on color monitors. Programming was added to the microcomputers to generate displays of unit location and status as overlays on the maps.

MACE can accommodate armor, airborne, airmobile, cavalry, regular and mechanized infantry maneuver BNs, and their combat/combat service support elements. The simulation provides real time outputs for battle assessments, casualty reports, ammunition and supply reports, and personnel reports. The free play feature of MACE provides the BN commander and his staff with a realistic combat situation to exercise their command and control techniques against an adversary who can adapt and respond to BN actions. The scenarios that can be developed are bound only by the availability of exercise area maps on the videodisc.

Operational Configuration

The MACE/Micro-Disc System in the BSC control room is organized into five operating stations corresponding as closely as possible to BN operational requirements (Figure 3). There are some constraints due to the design of the software and the allocation of operations to different microcomputer modules.

The main game control station has positions for the exercise director, the chief controller, the OPFOR team chief, and the BDE S2 and S3 player/controllers. It is the responsibility of this group to ensure the smooth functioning of the simulation, and proper use of each of the other modules of the system. A large screen display is operated from the main game control station to provide a common display for reference when individual stations are focusing on different areas of the battlefield.

At each of the two maneuver/conflict stations, the player/controllers determine friendly and OPFOR company level actions, and provide coordination between the maneuver companies, other BN elements, and BN and BDE headquarters. Friendly company maneuver commands are determined by the company commanders based on BN orders and their own judgment. The OPFOR player determines commands for his forces in coordination with his team chief at the main game control station. Both friendly and OPFOR commands are entered into the station's maneuver/conflict microcomputer module. The controller is responsible for ensuring accurate inputs and for initiating conflict when it is appropriate. The map and overlay display at this station supports the development of the command inputs with detailed unit location, status and action information. The company commanders at each station are assisted in their work by one company executive officer (XO) or first sergeant (1SG) and the Fire Support Team (FIST) member. In addition, the XO or 1SG provides coordination with BN staff and with the admin/log station. The FIST provides coordination with the fires/air station.

The admin/log station has two positions. One position is for the BDE admin/log controller who is responsible for the input of brigade responses to requested support from battalion admin/log. The other position is the BDE S1/S4 player. The S1/S4 player receives status

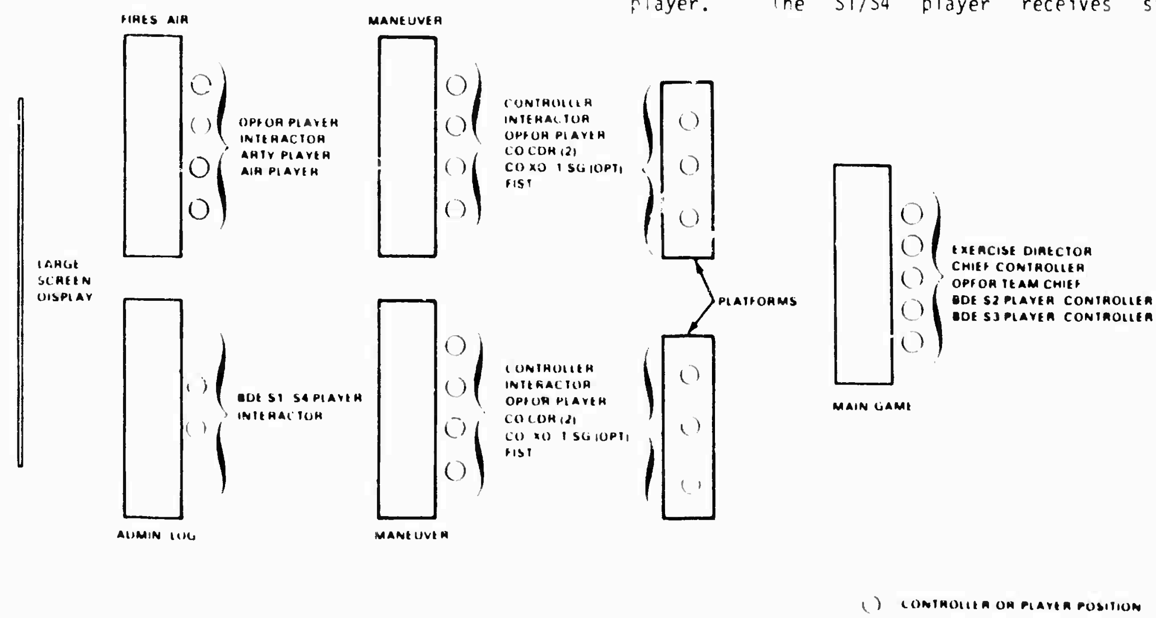

Figure 3. BSC Control Room Layout.

reports, and processes requests for supplies and personnel from the combat trains.

The fires/air station has an OPFOR player to determine enemy artillery and air actions. The artillery player coordinates the requests for artillery support. Requests for air missions are coordinated by the air player.

Operator Station Description

At a typical operator station (Figure 4), there are two microcomputers and associated input and display peripherals. The data system microcomputer generates results for a portion of the simulation such as maneuver or admin/log. The graphics system microcomputer drives a videodisc player and a graphics generator. The graphics generator mixes the map background video from the videodisc player with symbolic overlay video to produce the current situation map on the video display.

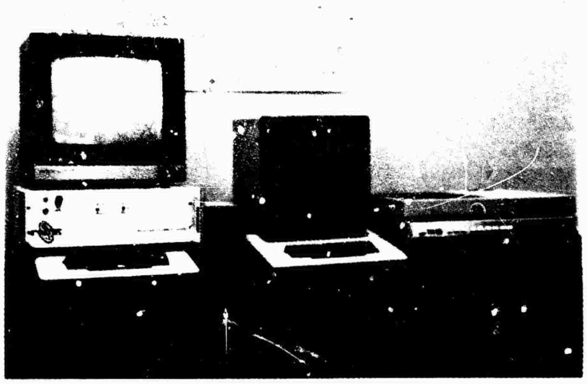

Figure 4. MACE/Micro-Disc Operator Station.

Maneuver, admin/log, and fires/air commands are entered through the data system microcomputer keyboard or the video system graphics tablet. Keyboard entries to the video system microcomputer call up the map display and a joystick provides scroll and zoom control. Information for the associated overlay is entered through the keyboard or a graphics tablet. Maneuver commands, admin/log commands, and fires/air commands are also entered through the keyboard or graphics tablet.

Operation of a MACE station is similar to CAMMS in terms of the computer interaction for command input and text display. Army personnel experienced in the use of CAMMS have been able to operate command input and text output with little additional instruction. About five hours of training and practice is sufficient to acquaint player/controllers with the MACE keyboard command, graphics tablet procedures, and joystick control of the map displays and overlays.

The Map and Overlay Display

A typical MACE/Micro-Disc System display of a military map from a videodisc and the associated unit status overlay is shown in Figure 5. The operator can use the joystick to scroll across the map display and zoom in on a section of particular interest. The zoom control permits selection of a display ranging from 40 to 4 kilometers on a side. The unit status overlay is keyed to the map coordinates, and moves with the map as the operator exercises the scroll and zoom features.

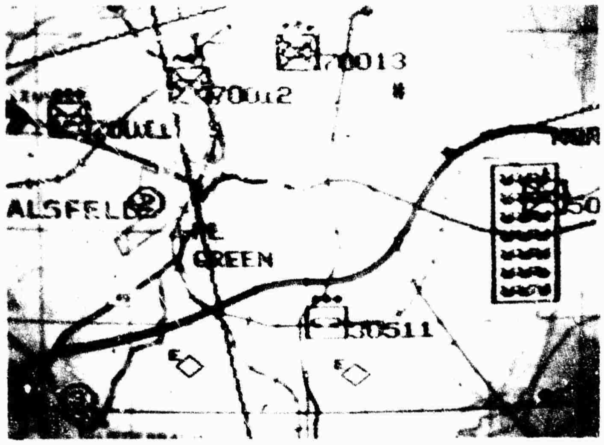

Figure 5. MACE/Micro-Disc Display of Map and Overlay.

MACE/Micro-Disc System Distributed Architecture

The Micro-Disc System distributed architecture provides common use of mass storage, access to all simulation functions through each microcomputer, graceful degradation in the event of microcomputer failure, enhanced continuity of the situation display and ready expansion. In the Micro-Disc System the microcomputers are interconnected by a local area network with a shared hard disk mass storage device (Figure 6). There are five modules, corresponding to the operator stations shown in Figure 3 and the organization of the simulation software.

The distributed architecture of MACE provides a number of advantages:

(1) FLEXIBILITY - Any of the functional modules, such as fires/air, may be run from any of the operator stations, provided that the appropriate peripheral devices are attached.

(2) CONTINUITY - If isolated equipment failures occur during an exercise, it is possible to reconfigure to run in a somewhat degraded mode and avoid sacrificing time already invested. For example, if the admin/log data system microcomputer fails, one of the two maneuver stations can be reconfigured to perform the admin/log function. Only one maneuver station would then be on line, but all module types would be active.

(3) SYNERGISM - Because of the shared file conceptual approach utilized by MACE, combined battle effects can be taken into account. For example, movement orders given to an engaged unit will produce a rate of movement which is affected by such factors as suppression, weather and terrain conditions.

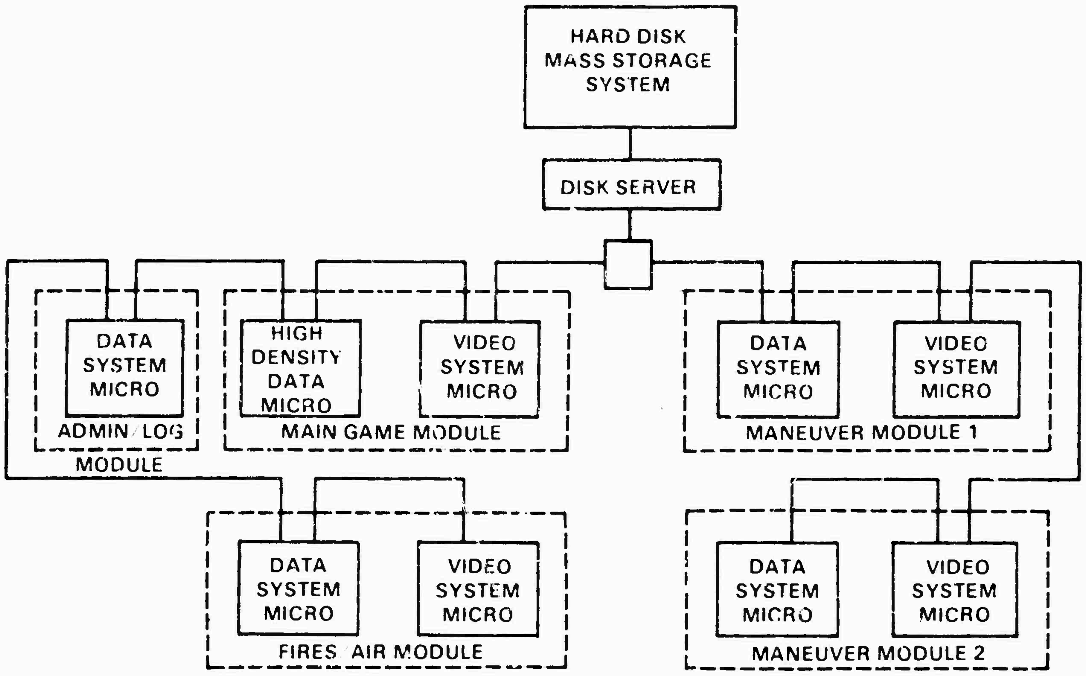

Figure 6. MACE/Micro-Disc Architecture.

The MACE/Micro-Disc System Components

The components of the MACE/Micro-Disc system provide proven operational capability, high reliability and low cost. The microcomputers, for example, have a negligible rate of failure except in cases where they have been mistreated (e.g., by inserting or removing an interface card before the power has been shut down). The hard disk, while the most sensitive piece of hardware, has a very large mean-time-between-failures and has weathered development and testing very well. The video equipment also has proven to be quite stable. Once adjusted, the graphics generators have continued to operate without any significant down time.

Operationally, the various components of the MACE/Micro-Disc System have performed well. The graphics system produces clear, medium resolution symbolic overlays on quite readable map backgrounds. The graphics tablets allow for rapid input of scenario data. The microcomputers have demonstrated their ability to do all the requisite processing in near real time to allow a realistic BN simulation.

The local area network implementation provides the necessary hardware linkage to multiply the effective computing power of the individual processors by allowing them to share access to the same data base.

Microcomputer ruggedization provides important reliability modifications by simplifying the connections to the computer while limiting access to printed circuit boards (Figure 7). These ruggedization modifications are such that all connections for peripherals are made on the back panel connectors of the microcomputers. To ensure proper connections are made, each peripheral has a unique connector which is clearly marked. The modifications also include a six ampere power supply and an internal computer fan with baffling system to prevent the interior components from overheating. Flexibility, durability and ease of use are greatly enhanced by these modifications.

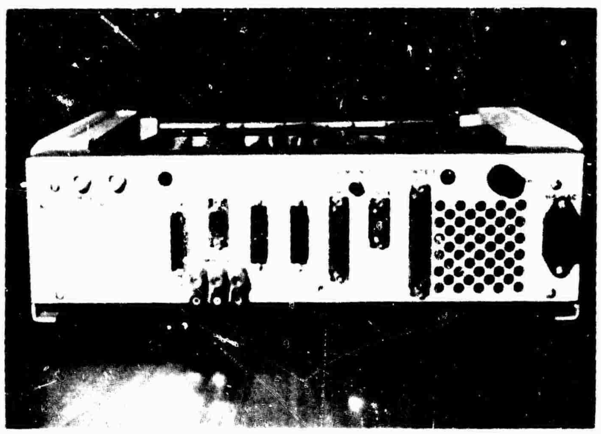

Figure 7. Microcomputer Ruggedization.

OPERATIONAL TEST RESULTS

Operational tests of the MACE maneuver BN-level training system were conducted at Fort Lewis, Washington during the months of February and March 1982. The tests were conducted through the exercise of five BN command groups of the 9th Infantry Division. Acceptance of the simulation as a training system was extremely high among the participants.

The tests established that:

(1) it is possible to convert the existing CAMMS program to operate on a distributed network of five microcomputers;

(2) the Micro-Disc hardware is cost-effective;

(3) non-ADP (automated data processing) personnel can operate the MACE/Micro-Disc System;

(4) no additional training aides are needed to support BN-level CPXs; and

(5) storage capacity for data in the MACE/Micro-Disc System is sufficient.

The tests also showed a need to declutter the graphics display and speed up processing to avoid simulation delays when 25 or more units are active. The latter requirement led to the investigation of a more powerful "high density data" microcomputer to be used in the main game module in place of the original data system microcomputer. Improvements to the graphics software have been identified and will be incorporated in operational versions of the MACE/Micro-Disc System.

BN commanders and their staffs participating in the Ft. Lewis tests rated the MACE/Micro-Disc System higher than CAMMS or manual CPXs. Those with CATTS experience rated MACE as comparable to the more complex and higher cost system.

CONCLUSION

The MACE/Micro-Disc system has been shown to be effective, easy to use and low cost. It is a system that meets the Army's need now for improved C^2 training at the maneuver BN level. Furthermore, it demonstrates what can be done with rapidly emerging microcomputer and videodisc technologies combined with distributed processing concepts.

The growth potential of the system ensures a long and effective life for the concept. The ability to substitute more powerful microcomputers, such as being considered for the Main Game Module, and the ability to network up to a total of 64 microcomputer devices provide major growth potential. More complex simulations can be readily accommodated.

The operational capability of the BSC can be further enhanced by adding new software modules for non-maneuver BN training. This can include engineer, medical and artillery BNs.

The growth potential in the use of the current configuration is perhaps equally important. Local needs for individual or small group specialized training can be met by using the Micro-Disc System for other war games or training packages when it is not in use for MACE exercises.

Finally, the Army has an opportunity to put a large number of systems in the field. This greatly expands the amount and quality of training of local commands, and creates an enormous base of information on what works and does not work in the field. That information, properly gathered and analyzed, can shape even more effective training systems for the future.

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OVERVIEW OF AN ONBOARD OPERATIONAL TRAINING DEVICE

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ABSTRACT

In order to optimize the capability of today's ASW equipment, an operator must be proficient in both the technical and operational aspects of system employment. Providing adequate training to personnel, however, is straining present resources. An effective onboard ASW training and readiness assessment capability that uses available shipboard personnel and equipment is one way of meeting future training needs. This paper provides an overview of an onboard training device that is now installed aboard SSN submarines. The various issues and lessons learned during system definition, development and fleet evaluation will be discussed, and the system approach and implementation will be described.

THE NEED

Advances related to the Soviet sea warfare threat, both in the areas of increased tactical capability and increased numbers of vessels, have been countered by a strategy requiring rapid increases in the capability of our antisubmarine warfare (ASW) systems. To ensure that our new systems are effectively used requires that the operators have an extensive technical and operational understanding of system employment. Optimum utilization of personnel and equipment to meet changing requirements requires continuous modification and evaluation of operating guidelines. Proficiency in all areas of maintenance, operations and tactical employment must be maintained at a high level to take advantage of our qualitative performance superiority.

The complexity of the systems has led to longer training periods. This period has aggravated the problem of optimum usage of personnel. As many as 21 percent of total Navy personnel are in training at any time. The lack of availability of trained people coincides with a rapid turnover of experienced fleet personnel. These senior people, with many years of practical knowledge, have been invaluable as educators and trusted advisors. These ASW operations "mentors" in the past could provide a level of experience and knowledge that could be used, especially aboard ship, to ensure the continuous proficiency of the sonar operators.

The problems associated with continuously evolving tactical equipment and operational guidelines, lack of qualified personnel, rapid turnover of experienced operators, and the ever-expanding training requirements, must be dealt with to ensure an adequate utilization of our advanced system capability.

BACKGROUND

Over the past ten years, Raytheon Submarine Signal Division has been involved in a novel approach to providing ASW training with the development of shipboard training equipment. Though onboard training is not new, the capability of providing realistic operational training while using the actual shipboard tactical equipment and environment has only recently been technically practical. Previously, the equipment necessary to adequately perform the signal processing functions needed would have been too large to be placed aboard the ship. Such devices were only considered for large shorebased training facilities. With the electronic advances in the area of large scale integrated circuits, especially the development of the microprocessor, a sophisticated training system could be developed for shipboard use. Initial development of the concepts used today began in the early 70s Raytheon developed a system that could stimulate the actual ship's sonar system with synthesized acoustic signals. It was originally conceived as a maintenance aid for the AN/BQS-13 sonar system used on nuclear attack submarines. However, it rapidly became obvious that such a system could provide a unique training capability of unmatched flexibility and realism. By injecting a synthesized signal into the sonar system, appearing to the operator as an actual contact or target, it was possible to train the operator repeatedly and predictably on his "own" equipment at any convenient time. The ability of the system to provide effective onboard training was successfully evaluated by the Navy in 1973, when an engineering development model of the trainer was tested (Figure 1). With this evaluation, a new alternative to providing and maintaining sonar operator proficiency was demonstrated.

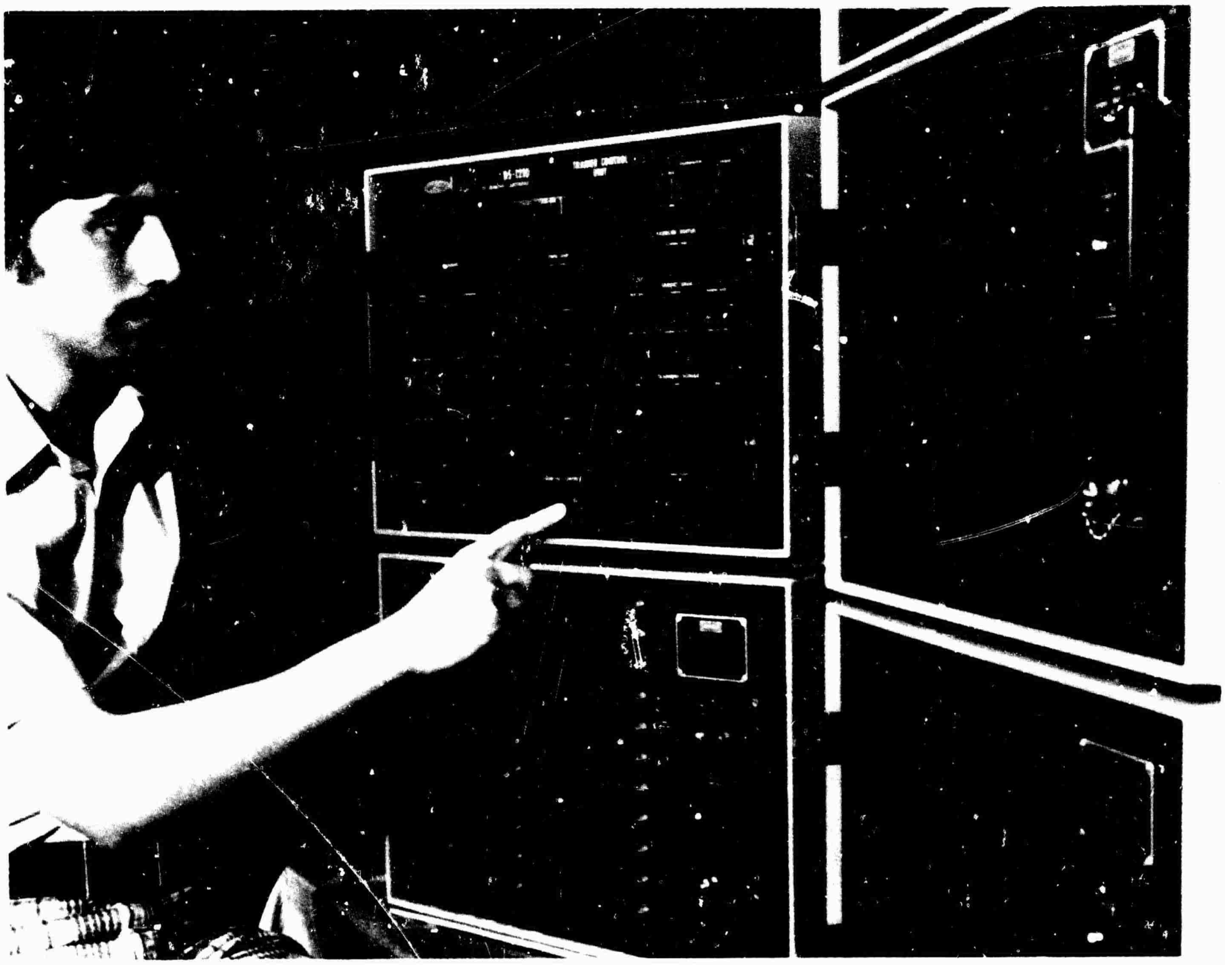

Figure 1. Preproduction Version of the AN/BQR-T4, the DS1210

ISSUES

The evaluation of this early system as an onboard operational training device uncovered several issues that have influenced the development of succeeding systems; they are:

- Ease of operator control of the training system
- Consistency
- Target realism.

Ease of Operator Control

The training system is used aboard ship, in many instances at sea, by shipboard personnel who are not instructors. Under these circumstances it is important that the control of the training device be as straightforward as possible. The training device is used to create a training environment. In order to make this as effective as possible, there should be very little overhead relative to turning on and setting up the system. It should be as easy as possible to get into the training exercise.

Consistency

Along with the consideration that the control of the training system be as straightforward as possible to conduct a training exercise easily, it is vital that the training environment that is created be as consistent as possible with the normal operational conditions expected by the sonar operators. This consistency is very important. There is no instructor, as at a shorebased facility, to provide the continuity needed if the training situation does not match the true operational conditions. The realism provided by the training device must be sufficient to allow the student to perceive a situation as consistent with his past training and operational experience. If not, the inconsistencies will interfere with the training process. Without an instructor to explain away major inconsistencies, the risk is that the training could be perceived as not appropriate and the training device might not be used at all.

The consistency issue applies to many aspects of the training environment, including turnon, setup, and employment of the tactical system, whether it be an individual equipment or the entire sonar ASW group. Ideally, the training system interaction with the tactical equipment is transparent so that no unique setup of the tactical equipment is associated with the training system being on. All operational modes should be available to the operators so that training can include turnon, setup, detection, classification and localization in a manner consistent with what the operator should expect when he is using his equipment properly.

Target Realism

In order to provide the possibility of training for the large variety of conditions that an operator is confronted with during the detection, classification and localization of a target, it is important that the training device provide a realistic training target. Here again the issue of consistency is important. If an operator is to be trained to best use his equipment to extract the maximum amount of information, it is important to provide the capability to exercise the operator in a manner as consistent with normal conditions as possible. Target type, signal content, narrowband and broadband, ownship and target maneuvering, and sonar signal processing setup can create many conditions that cause unique presentations at the operator's sonar display. By providing a reasonably realistic training target, an operator can be taught to recognize and respond to the key characteristics that allow him to best employ his sonar system.

Particular attention must be paid to areas where cognitive decision-making takes place. Subjective analysis of target characteristics as seen on sonar displays is an area that requires repetitive training to maintain proficiency. By providing a realistic target and allowing the operator free play in the use of his equipment, he can best appreciate the interaction of incorrect equipment settings on the degradation of the detected target signal.

Now in Service Use

These issues provided the basic guidance in selecting the particular system approach and implementation used during the development of the production version of the training device.

The first production version of the onboard trainer was the DS1210. The system has received approval for service use, is installed on all fleet ballistic missile submarines and has been assigned the military designation AN/BQR-T4.

Over many patrols, combat teams have been enthusiastic about the high degree of realism which the trainer makes possible. The concepts originated to evaluate the first training system have been expanded to a sophisticated training program known as SOTAP: Sonar Operational Training and Assessment Program. SOTAP is a Navy-managed program used to coordinate sonar operator training to ensure optimum use of both the shorebased training facilities and the onboard training equipment.

Front-End Stimulation

The success of the onboard training system in providing an effective capability is due to the design approach chosen and its implementation. The DS1200 series trainers are "stimulation" type systems rather than "simulation" systems. The primary functional difference is that the stimulator uses as much of the tactical sonar equipment as possible where as the simulator type system "simulates" mathematically as much of the equipment as possible. With the stimulator, the goal is to model the threat and acoustic phenomenon as realistically as practical, synthesize analogous signals, and stimulate the sonar with these signals. The fact that the actual sonar system equipment is used to process the signals provides a very realistic presentation to the sonar operator. It is this realism that allows training to take place on many levels, from simple procedural training to levels that require an interpretive assessment on the part of the sonar operator to ensure proper utilization of the sonar equipment. To date, the degree of realism attained with stimulation has not been reached using the simulation approach. The complexities of the ocean medium and the difficulty of modeling the sonar system processing have made it impractical when a high degree of fidelity is needed.

The signals generated by the training system are injected into the sonar system as close to the "front-end" as possible (See Figure 2.) This allows all sonar

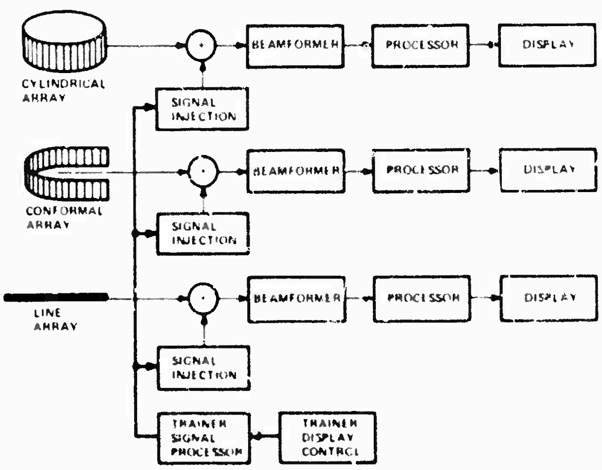

Figure 2. Flow of Injected Synthesized Signals

processing to continue during the training exercise. It also does not interfere with normal operator functions. The operator does not have to configure the sonar into a "training" mode; therefore, the operator is trained in an environment consistent with the normal operation of the tactical equipment. Added advantages to front-end stimulation are that test signals can be injected into the sonar system for maintenance purposes, any auxiliary processing equipment used with the sonar can also be stimulated, and the trainer system is relatively immune to changes that may take place to improve the processing capability of the sonar system.

The signals injected into the sonar are synthesized replicas of signals normally expected from the transducer array assembly. The training system has to have within it a "world of its own." The training system provides its operator the capability of selecting various target and ocean types. The selected target vessel can then be maneuvered as though the trainer operator, using the instructor's console, were in fact the target vessel operator. (Figure 3.)

Within the equipment, the maneuvers of the target and ownship are monitored and maintained. The radiated target vessel signals are synthesized to reflect the varied characteristic of machinery, propulsion, propeller and hydrodynamic sound sources. These radiated signals are modified to reflect the complex nature of propagation through the selected ocean. An array simulator then processes the signals to reflect the conversion of the synthesized sound pressure signal by the sonar transducer array assembly. These signals are then injected into the sonar to be processed as actual acoustic data (see Figure 4).

Of particular interest is the complex nature of the radiated spectrum from the target vessel. In order to realistically simulate these signals, the training system must be able to recreate the "insides" of the selected target vessel.

The sounds from auxiliary equipment, diesel-engine firing, the whine of gears, the hum of generators, propeller cavitation, and water flowing over the hull are characteristic sounds that provide clues to the sonar operator of the vessel

Figure 3. Trainer Control Unit of AN/BQR-T4 as Installed in a Fleet Ballistic Missile Submarine

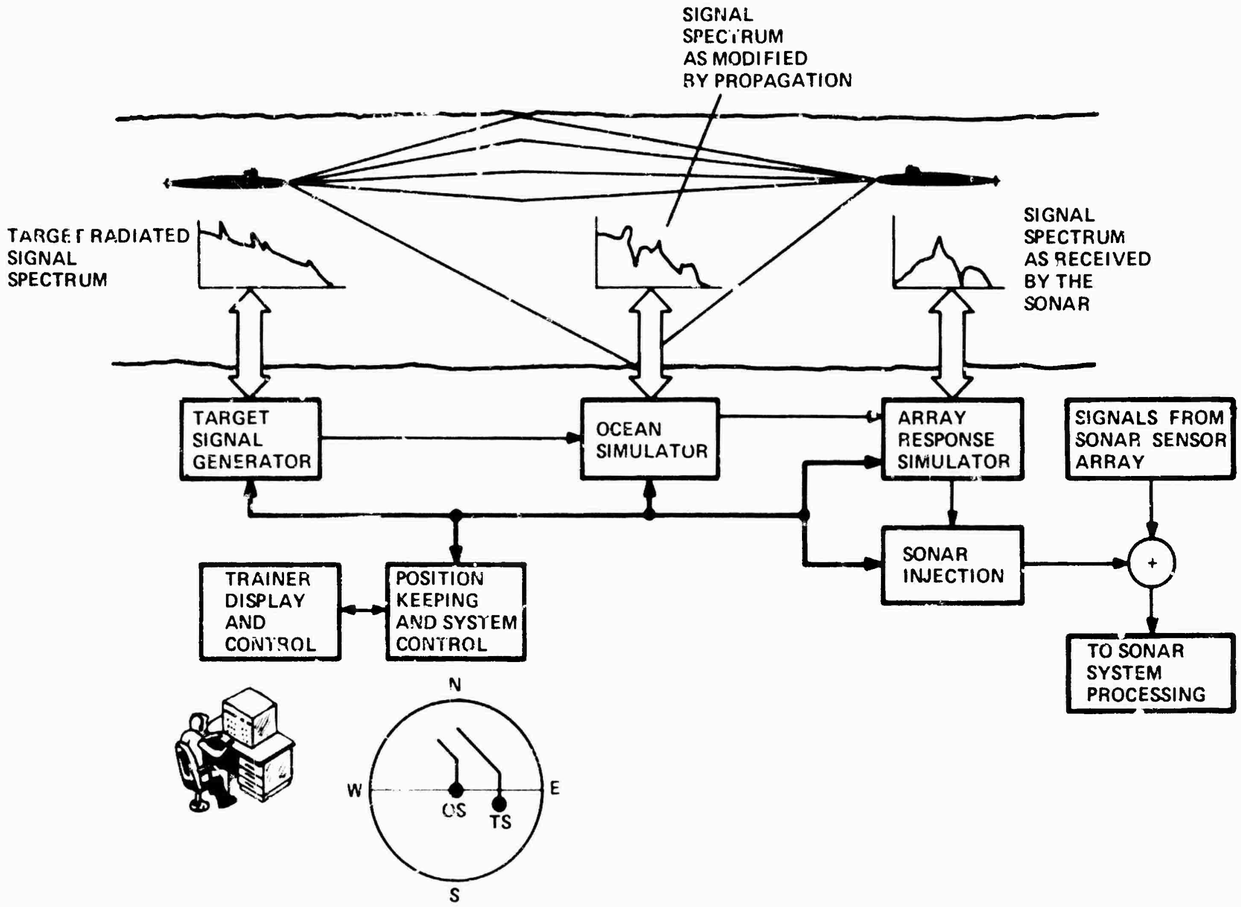

Figure 4. Trainer Simulated World

type. These various characteristics are synthesized by a microprocessor-controlled digital signal generator that is programmed to model various target types (see Figure 5).

The system approach allows for ready adaption to different sonar systems. The target signal synthesizers and the ocean processing have been designed to approximately model the effects of the respective phenomena, independent of the tactical system to be stimulated. The training system's array simulator can be programmed to model various geometric configurations of sonar system sensor arrays. It is the function of the array simulator to provide the unique processing needed to adapt to various sonar system characteristics

The system concept described has been successfully applied to submarine and surface ship sonar systems. Newer versions of the system allow for multiple targets to be synthesized and controlled simultaneously. Evolutions of system capabilities have led to ownship noise and ocean noise synthesis to allow realistic dockside training to be conducted.

Ownship motion is simulated so that, dockside or during transit periods, the training can allow own ship to prosecute the training target without interfering with normal evolutions. Interfaces have been provided with the fire control system aboard ship so that an entire fire control, sonar team exercise can be run. In fact, any combat system function that is provided tactical information from the sonar can be exercised in a training situation.

THE FUTURE

The future of the onboard operational trainer can lead to a means of providing a source of information that previously was supplied by key experienced personnel or mentors. This capabili[illegible] can be provided to the ASW team or in fact, any sensor or combat team. A trainer can be configured for each major sensor group and it can become a source of operability

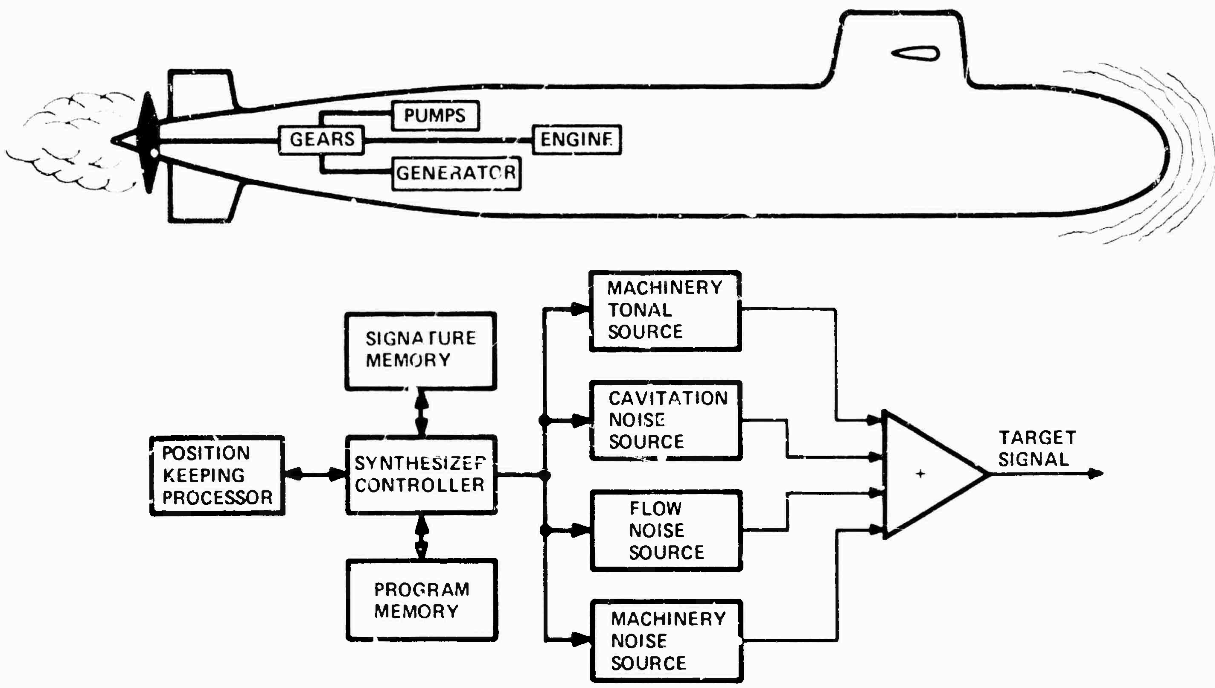

Figure 5. Microprocessor-Controlled Synthesizer

information providing not only a training capability but a library of operation guidelines, a source of maintenance information, and also an interactive means of managing operations for each team. Basically, the system can become a permanent source and focus of information storage that can aid with the operations, maintenance, training and readiness for the sensor team: a source that is consistent from ship to ship and a permanent complement to the ship's force.

ABOUT THE AUTHOR

Joseph Ricci is a senior engineer at the Submarine Signal Division of Raytheon Company. He was the lead design engineer for the development of the DS1200 and DS1210 training systems. He is currently providing technical direction for the development of future DS1200 series trainers. He joined Raytheon in 1970 after receiving his BSEE from the University of Rhode Island.

THERMAL SIGNATURE TARGETS

FOR

GUNNERY TRAINING

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Project Director
PM-TRADE, Orlando, FL

ABSTRACT

The United States Army has achieved a significant advantage over the Warsaw Pact forces in the area of tank gunnery under conditions of darkness, smoke, fog, and rain. This advantage has been gained through the development of the tank thermal sight. The ambient temperature, under virtually all environmental conditions, including smoke and darkness. Since the Soviets are particularly adept at fighting under cover of smoke, the ability of U.S. gunners to acquire a high skill level in the use of the thermal sight is imperative to allow rapid acquisition and identification of enemy vehicles and personnel.

Gunnery training under adverse conditions of darkness, smoke, fog, and rain are now being conducted with the aid of a thermal signature target developed through PM-TRADE. The background leading to the development of a Thermal Signature Target as well as a detailed description of a modular, full scale tank Thermal target system is presented.

INTRODUCTION AND BACKGROUND

In anticipation of fielding several weapon systems which employed thermal sights, the Army issued a requirement for the development of targets which could be used in training gunners associated with those weapon systems. The requirements at that time were rather sketchy since such training had never been conducted. The first thought was to require targets which presented an exact thermal signature of the vehicle or subject being represented. Details of road wheels, tracks, engine box and exhaust, turret and gun tube were specified as distinguishing features. Although the cost of such a target would be relatively high, it was felt that target recognition and identification were significant elements of training.

Of concern to the Army was that the targets be low cost, have low maintenance requirements, and that installation could be completed quickly. In addition, the Army was particularly concerned about power requirements for the thermal targets. A thermal target which required no external power supplies such as batteries, generators or commercial power was the Army's goal.

During the early development of the thermal target, several candidate targets were presented to the Army by various government and commercial agencies. The forerunner in the thermal target area was NTEC, Orlando. (1) Only one target which was demonstrated required no external power supply

The initial technique selected by the Army to fill the requirements for a thermal signature target involved a chemical heating process. The chemical source was provided in the form of a salt which, when combined with water, generated heat.

Initial tests appeared to be successful; (2) however, subsequent evaluations of the chemical heating bag approach revealed several drawbacks, such as poor signature in cold weather; short duration of the signature before requiring a water refill; and the overall effort was very labor intensive.

The immediate requirement for a target which required no external power supply was dropped in favor of a target which could be powered by a 12 volt battery. That target system was developed by TVI Energy Corporation of Beltsville, Maryland. The TVI target is not considered to be the ultimate solution to the thermal target problem; however, it has been demonstrated to be a viable concept.

SYSTEM DESCRIPTION

Target Module

The TVI thermal target is made of modules which can be arranged in any order to form the desired configuration. Individual modules include track sections, turrets, hull sections and road wheels. A typical target system is depicted in Figure 1. This figure shows the standard target lifting mechanism with a NATO standard plywood target. Attached to the plywood target is the TVI thermal signature target. The configuration shown is that of a Russian T62 tank as viewed from the front. Modules can be stapled or tacked to the plywood target. Figure 2 shows the arrangement of thermal modules and also shows the interconnection of wires to the main target harness. Modules can be produced in basically any shape and size within limits. The various arrangements which are presently in use are shown in Figures 3 and 4.

There is a definite advantage to forming the thermal target with modular units rather than using a one piece target. It has been found that the majority of rounds strike the target at the center of mass; i.e., the engine box or the turret sections. Track sections are only occasionally hit. Therefore, it is necessary to replace only turret and the engine box modules normally, and, less frequently, the track modules.

With the limited data available to date, it is estimated that approximately ten 105mm rounds can penetrate a target module (approximately 50 per target) without severely deteriorating the image quality. This assumes that a round does not sever the electrical connections on that module. However it is possible to repair the electrical connections with a repair kit which is available. The limiting factor with the thermal targets seems to be a function of the survivability of the plywood to which the target is mounted.

A typical module is shown in Figure 5. The electro-conductive coating inside the flexible heating element operates as a wide area resistor. The actual resistance of each target module is a fixed value, with the resistance for each type of target module (i.e., track, road wheel, etc.) controlled to a relatively tight tolerance in manufacture.

When an electrical potential is placed across the coating, a current flows and power is dissipated. Thus certain target modules, depending on their predetermined resistance values, will appear cooler than others with the same supply voltage. This allows a complete thermal target to show a pattern of hotter and cooler target modules, without separate controls, while running off a single power supply. This provides the gunners with the indication that some of a vehicle's thermal "cues" are more intense than others (e.g., that an engine compartment is hotter than a turret).

The electrical current flow to the conductive coating is carried by the copper busbars. These busbars are located at opposite edges of the coating in a manner that promotes electrical current flow throughout the area of the conductive coating.

To ensure reliable and continued target operation even after live fire damage, the busbars in these target modules have power supply connections at both ends. Servering the busbar at any point only results in the loss of the signature from the area immediately around the hole.

Having redundant circuitry also means that the electrical connections to such a target module must be keyed for polarity. This is to ensure that both ends of the same busbar are connected to the same side of the power supply. Failure to do so could create a short circuit condition, potentially damaging to the power supply and control modules.

Heating element performance is enhanced by the presence of an insulating layer bonded to the rear of the target module. This layer of flexible insulation or styrofoam, depending upon the type of target module, thermally isolates the heating element from the cold plywood backing, minimizing energy loss by conduction to the plywood.

Power Supply

Although the Army continues to search for a target which will generate a thermal image without the need for an external power supply, the present target system does require power.

Since many of the ranges used by the Army are not equipped with commercial power, battery power is used extensively. And in keeping with this approach, batteries were used as the source of power for the present thermal targets. However, several problems appear when batteries are used to power a heat producing element such as the thermal target. The present targets generate approximately 10 watts per square foot of target area. Using a full size tank target, a standard 12 volt battery will dissipate very quickly if the targets are powered continuously. To alleviate this problem, a control mechanism was devised to provide power to the target only when the tank crews were in the ready-to-fire mode.

Since the targets are mounted on a lifting mechanism, target acquisition by the gunners occurred only when the targets are in a vertical position. If the target is not hit within 45 seconds, the lifting mechanism when in the automatic mode, drops the target to a horizontal position. In that position there is no need to generate a thermal image; therefore, power can be turned off. By placing a mercury switch on the lifting mechanism, the power to the target can be turned on as the lifting mechanism begins to raise the target.

The lifting time for the target mechanism is approximately 6 seconds. It was found that this time was not long enough to allow the target to fully heat when powered by 12 volts. To reduce the heating time, a battery inverter was included in the system. The inverter converts 12 volts to 110 volts. In addition, timing circuits were added to limit the time that power is provided to the target for each cycle. The time limit feature makes it possible to leave the target in the vertical position when the lifting device is in the manual mode without dissipating the battery. It was also recommended that the thermal signature be presented no more frequently than every 10 minutes. During this time, the battery can recover to a certain extent. The 10 minutes between cycles also more closely matches the training scenario.

With the aid of the inverter, or power control module, and a few new procedures, it was possible to increase the time between battery chargings to 8 hours with normal use. The power control module is mounted at the base of the target or on the target lifting mechanism as shown in Figure 1.

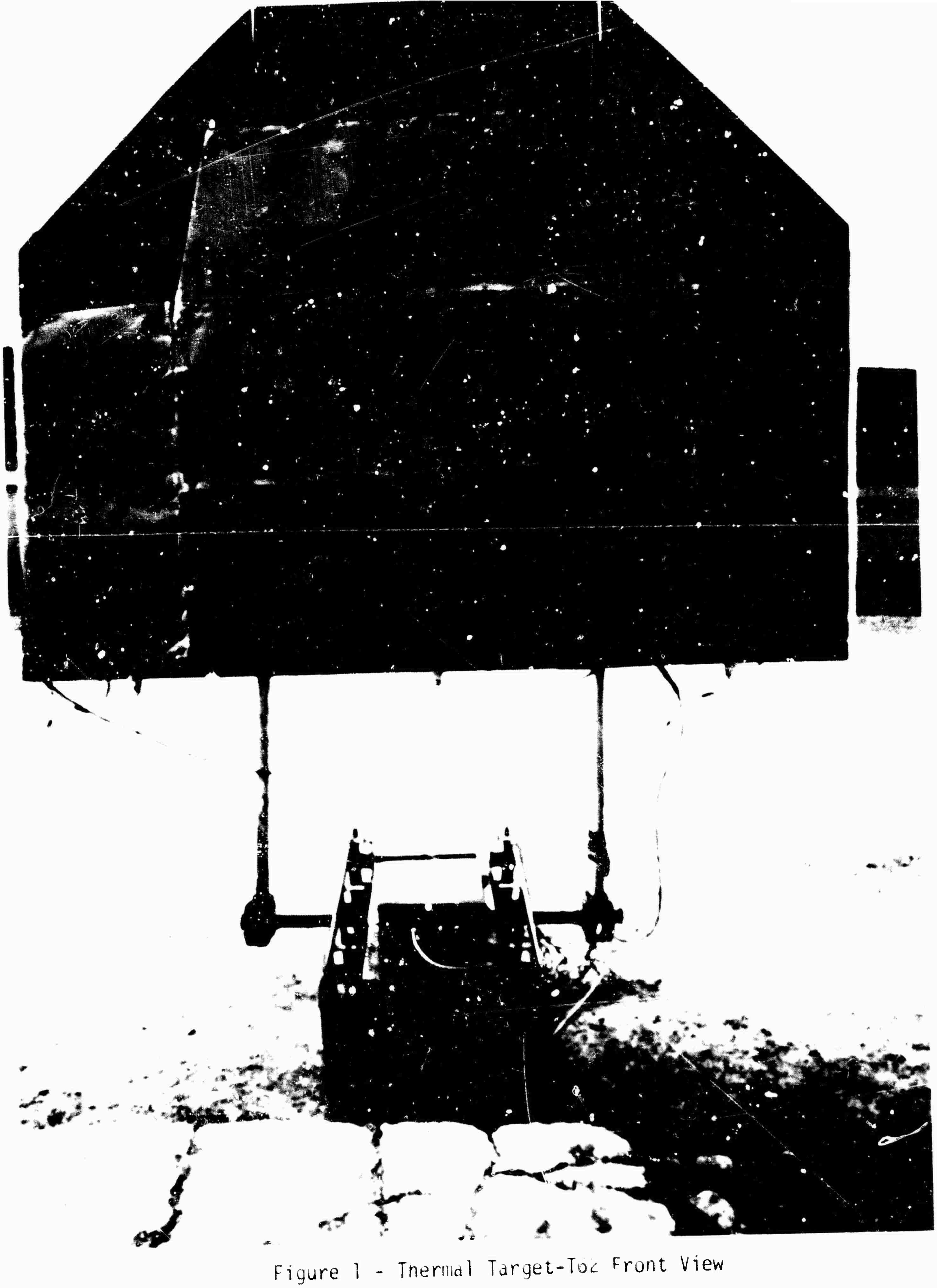
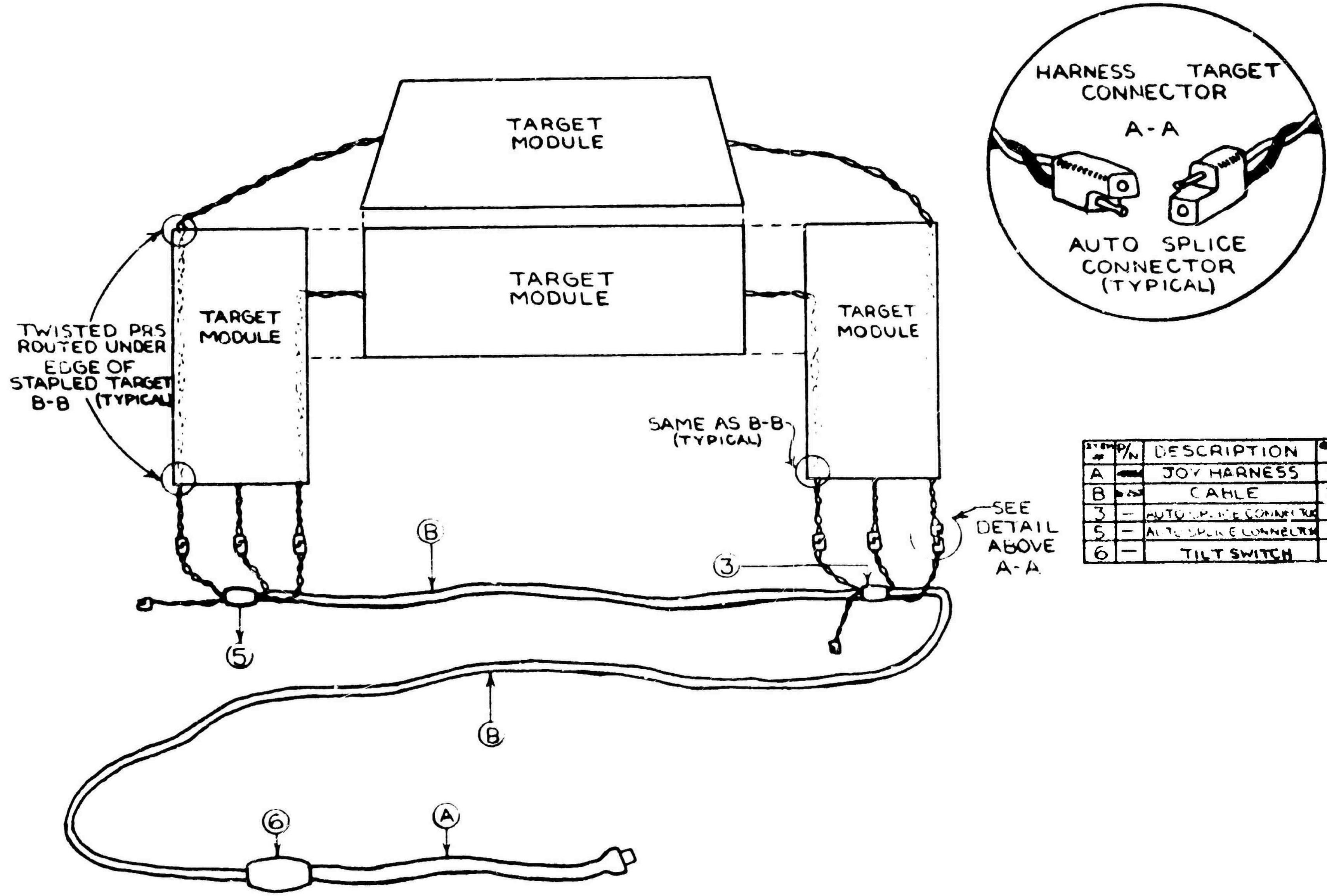
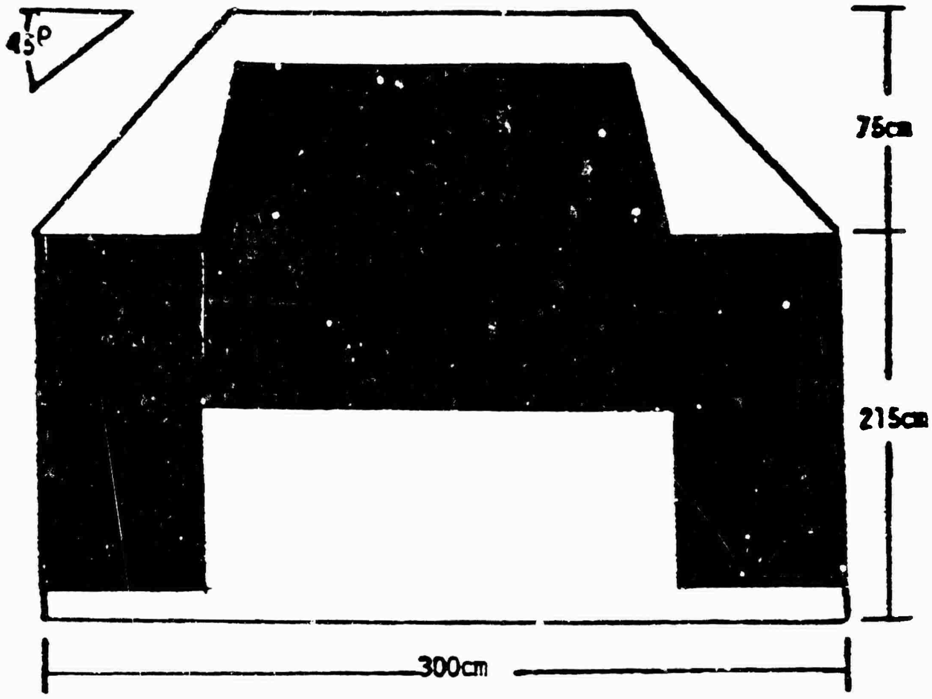


Figure 1 - Thermal Target-To2 Front View

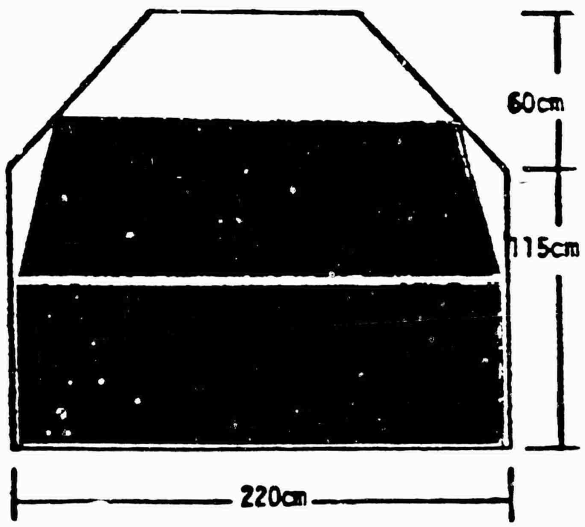


ITEM #	P/N	DESCRIPTION
A	[illegible]	JOY HARNESS
B	[illegible]	CABLE
3	—	AUTO SPLICE CONNECTOR
5	—	AUTO SPLICE CONNECTOR
6	—	TILT SWITCH

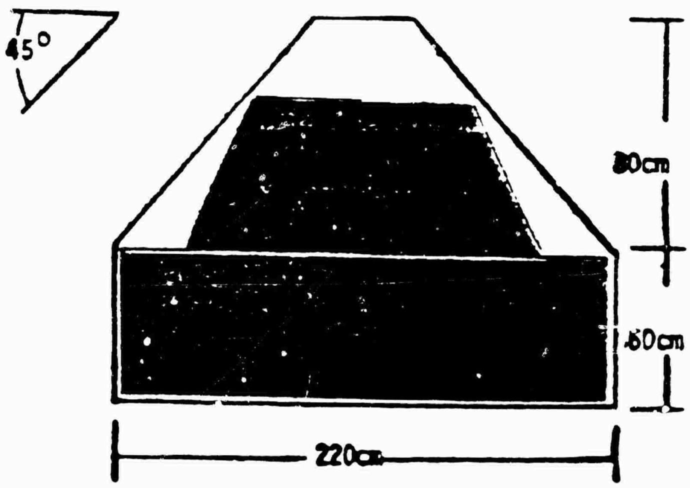
Figure 2 - Thermal Target Modules



NATO #70 Full Frontal

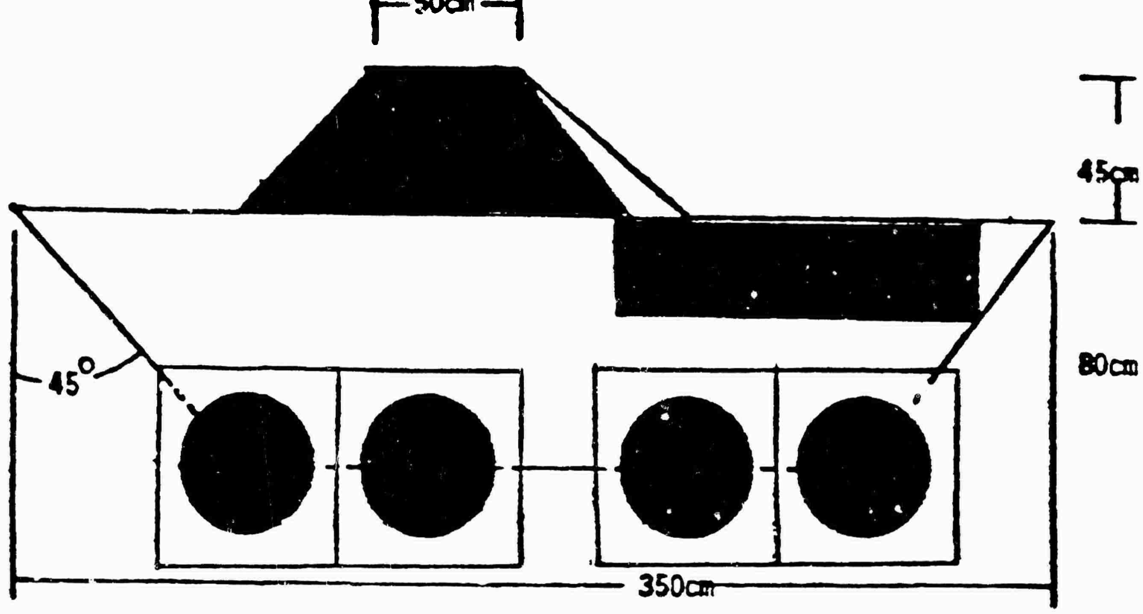


NATO #59 Partial Defilade.

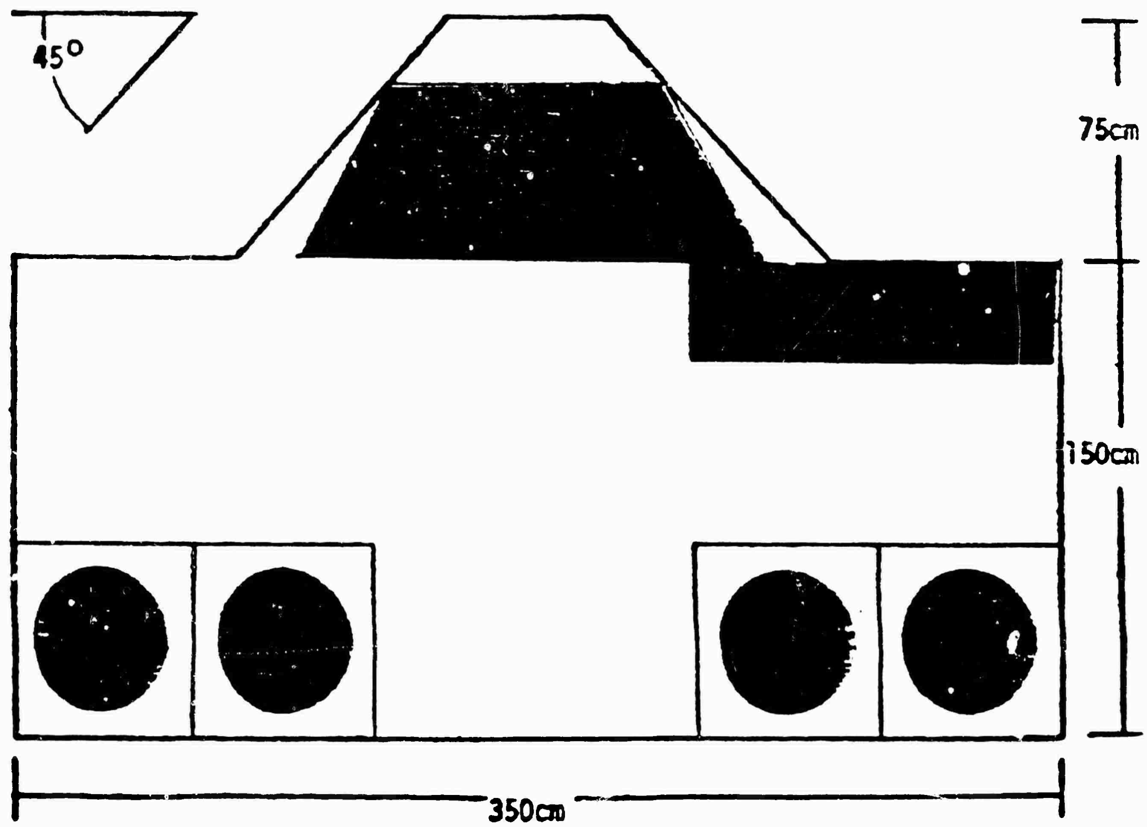


NATO #60 Partial Defilade.

Figure 3 - Thermal Targct Arrangements

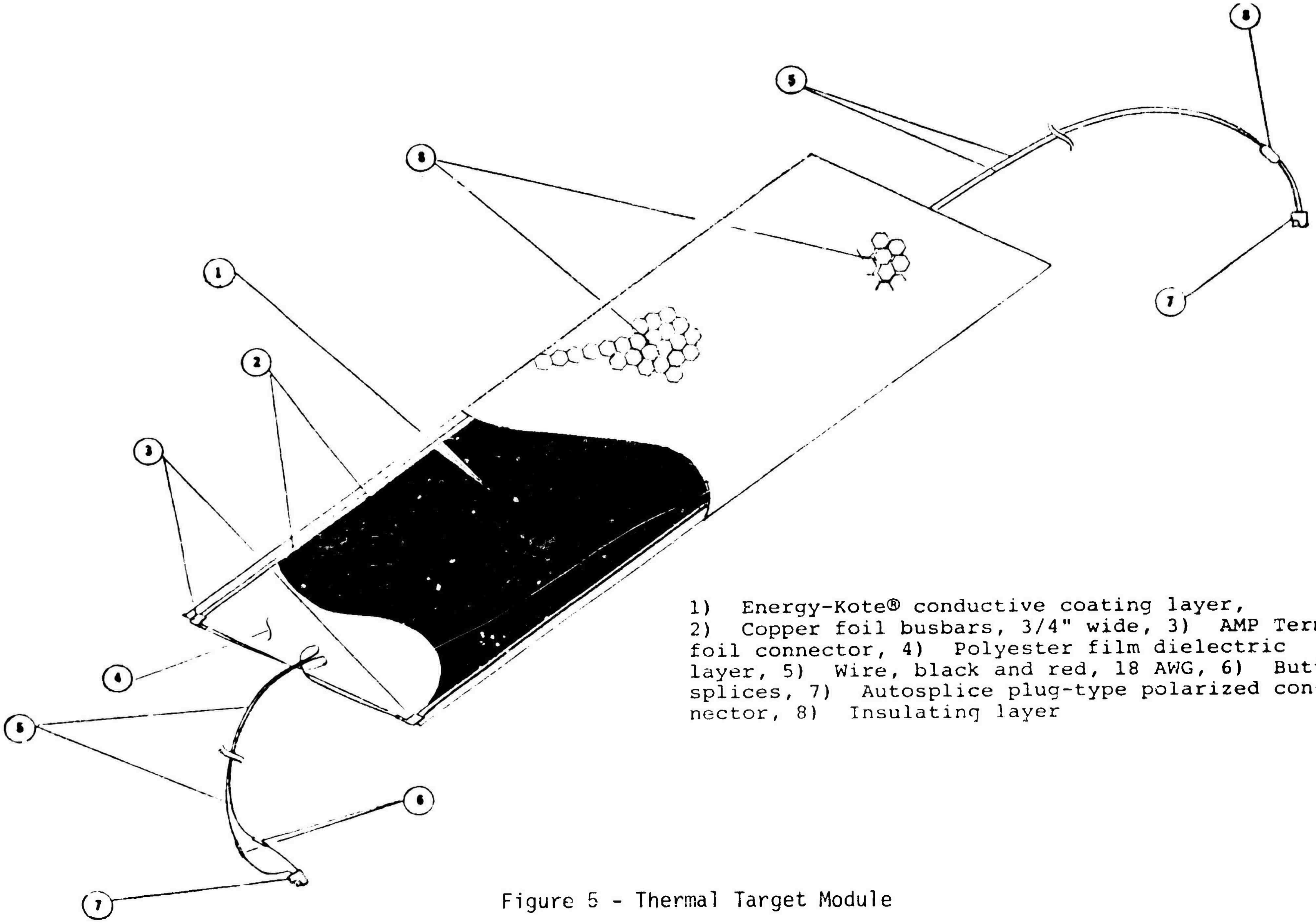


NATO #51 BMP Flank



NATO #58 BTR Flank

Figure 4 - Thermal Target Arrangements



1) Energy-Kote® conductive coating layer, 2) Copper foil busbars, 3/4" wide, 3) AMP Termi-foil connector, 4) Polyester film dielectric layer, 5) Wire, black and red, 18 AWG, 6) Butt splices, 7) Autosplice plug-type polarized connector, 8) Insulating layer

Figure 5 - Thermal Target Module

Alternate Power Sources

Battery power is perhaps the least efficient method of powering the thermal targets; however, the technology associated with their handling and maintenance is minimal. Therefore, batteries have gained widespread acceptance. On the other hand, gasoline powered generators are a considerably more efficient means of providing power. Due to a long history of being a maintenance nightmare, generators are generally avoided in areas where skilled repairmen are not readily available. The obvious solution would be to use commercial power. The installation of commercial power has the connotation of permanency, which means the ranges are no longer flexible and portable.

Despite the fact that all of the power sources described above have some disadvantages, the thermal target is not limited to any one source of power. The targets function equally well with battery power, generator power, or commercial power.

Thermal Target Training Environment

What will the trainee expect to see through his thermal sight? The answer is that the image is strictly a function of the thermal sight design. Since the image presented to the gunner is a video reproduction of data gathered by the thermal sensing devices, image quality and resolution vary considerably from sight to sight. A general representation of a thermal image of a tank at night is shown in Figure 6.

However, night sighting is only one condition under which the thermal sight is a very useful acquisition guide. The Warsaw Pact armored units are particularly adept at fighting under cover of smoke. As shown in Figures 7, 8, and 9, the battlefield can be cluttered with smoke which obscures the enemy, and by fires which can provide false thermal images to U.S. gunners. Therefore, it is essential that gunners receive adequate training in target recognition and identification under all conditions of nighttime, rain and smoke. Figure 9 shows a Soviet tank partially obscured by smoke cover. Figure 10 shows the same tank as viewed through the thermal sight. In addition to smoke cover, trees and brush are used to obscure enemy vehicles. Figure 11 shows a tank in partial defilade, and Figure 12 shows the same vehicle through the thermal sight. Again, these photos demonstrate the capability of the thermal sight.

To be able to distinguish the targets from the background requires that the targets used for training adequately define the target. A simple hot spot or blob target may not allow the gunner to recognize a target because of its similarity to the background, or battlefield conditions. A fire on the battlefield, for instance, will look the same as a hot spot target through the thermal sight. Therefore, negative training may be provided if hot spot targets, rather than well defined targets, are used during training.

Figure 13 shows a TVI thermal signature target through the M60A3 thermal sight. The target represents a front view of the T62 tank. Without proper training in target recognition, it would be difficult to distinguish the target from the background. The problem further increases as the range to the target increases.

Future Potential

Each new vehicle or weapon system which employs a thermal sight presents a new training problem. In addition to simulating vehicles, individual personnel and squads must also be simulated for training purposes. Targets which can provide full scale and reduced scale signatures, two dimensional and three dimensional views and be moving or stationary must be addressed. In addition, there must be a continuing effort to develop a target which requires no external power supply to produce a thermal signature. At the present time, this task appears to be beyond the present state-of-the-art. However, emerging technology may provide a solution to the problem.

CONCLUSION

The development of thermal signature targets through PM-TRADE has provided the Army with a simple, reliable and effective tool for training gunners to use the thermal sight. Efforts will continue to develop an improved target with particular emphasis on power requirements. The ideal situation would be to have a thermal target that required no power. However, unless a major breakthrough occurs, some form of power will be required to generate a thermal signature. The object of future efforts will be to reduce the power requirements to the lowest level.

Even as an interim solution, the TVI thermal signature target is a vast improvement over previous, antiquated techniques such as heating targets with charcoal fires or smudge pots. Characteristics such as quick installation, convenience in handling, low cost, modular form, and the ability to withstand several hits from tank main gun rounds make the TVI thermal signature target an extremely viable solution to the thermal signature target problem.

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2. Customer Tests of Thermal Signature Targets for Use with Combat System Thermal Sight, Armor Engineer Board, Fort Knox, KY, 3 October 1979.

ABOUT THE AUTHOR

Dr. Robert T. Dybas is the Project Director for the thermal signature program at PM-TRADE. He holds the degrees BME and MS-Engineering Mechanic from Rensselaer Polytechnic Institute, and an MS and DPA from Nova University. He has been involved with a variety of training devices and simulators at both PM-TRADE and NTEC. Primary involvement has been in the areas of gunnery trainers, maintenance trainers, and targets and ranges for training.

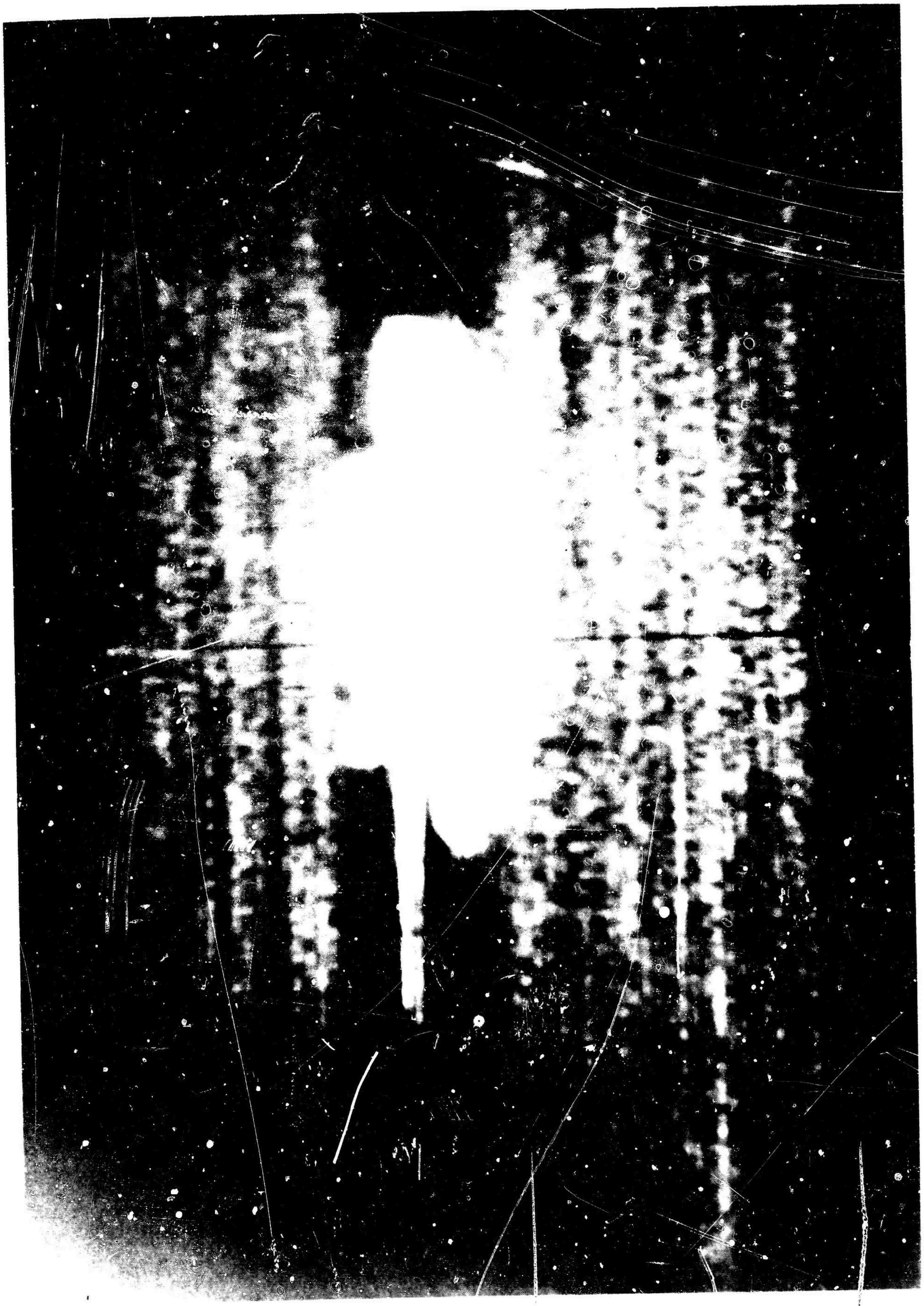

Figure 6 - Night Sight Thermal Image

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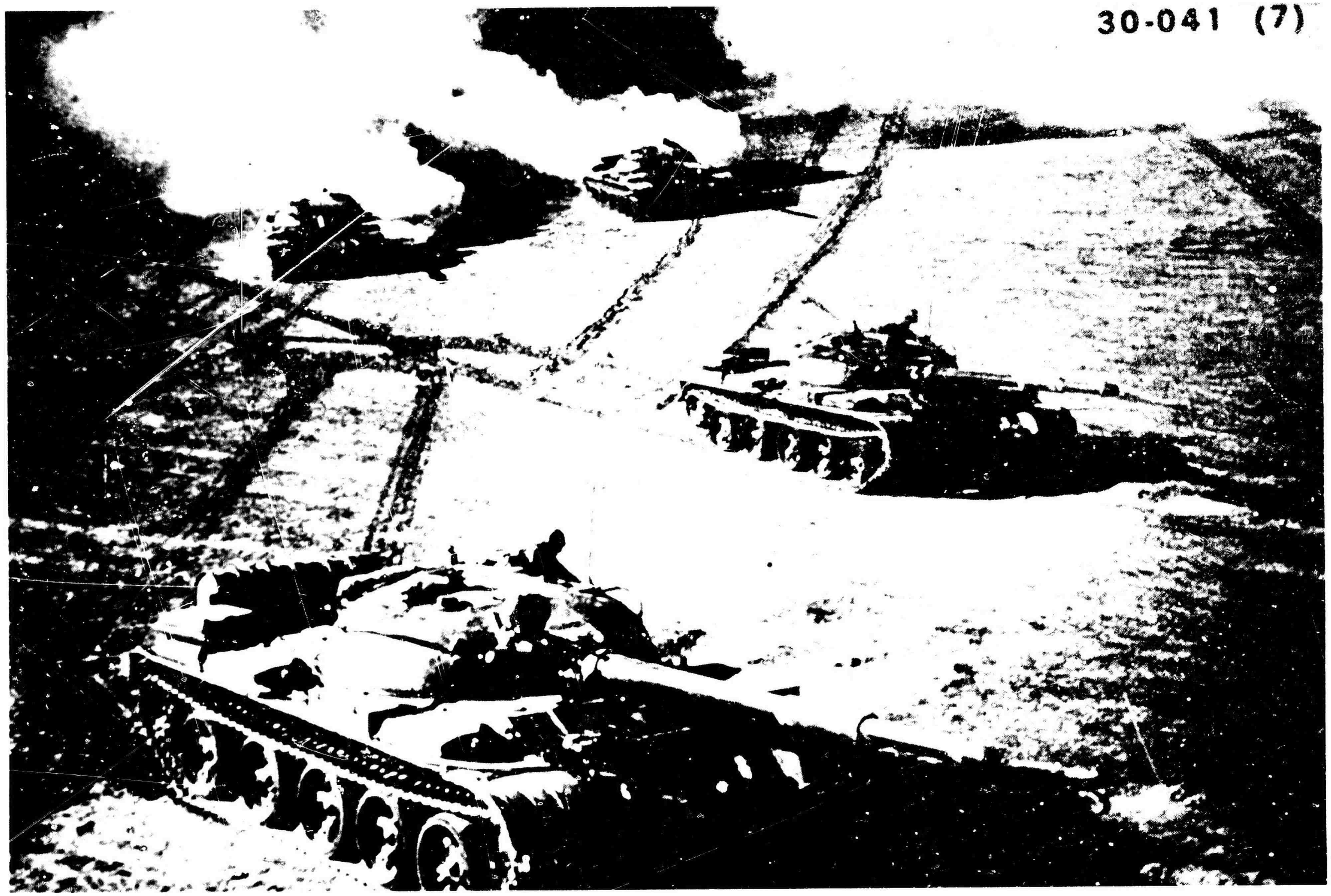

Figure 7 - Battle Field Conditions

Figure 6 - Battle Field Conditions

Figure 9 - Battle Field Conditions

Figure 10 - Thermal Image of Smoke Obscured Tank

Figure 11 - Tank is Partial Defilade

Figure 12 - Thermal Image of Tank is Defilade

Figure 13 - Thermal Image of TVI Target

AD P000164

THE VIEW FROM THE OTHER END OF THE MICROSCOPE
OR
I'D RATHER BE FLYING

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ABSTRACT

For years we have looked at the pilot, and (in our infinite wisdom), have decided among ourselves that the more a simulator looks, feels and smells like an aircraft the more capable a training device it will be. Granted, we have made great leaps forward in computer, visual and motion system technology, and convinced ourselves and many others of the great future of aircrew training devices. However, somewhere along the way to selling ourselves and the rest of the world, we forgot to convince the pilot. This paper takes a figurative walk through the last 20 years in the simulator world. It looks "back through the microscope" from the pilot's point of view. The accusation is that (despite our good intentions) we have 1) overestimated the simulator's capabilties; 2) failed to plan adequately for its use; 3) overemphasized fidelity in the place of training capability; and 4) overcomplicated these devices by trying to incorporate too many "whistles and bells." In doing so we have developed pilots who aren't fighting to "fly" simulators. The basic recommendation is that we as developers, buyers, and managers of aircrew training programs might better serve the pilot's and our needs if we did a better job looking at the simulator as part of a total training program rather than as an end in itself.

The scene: a Tactical Air Command Base somewhere in the southwest. The new mission simulator has been in operation for a month. The building is new and beautiful with efficient air conditioning, plush carpets, and comfortable briefing rooms. It's been said that this mission simulator will save lives, fuel, time and money. It has the latest technologies incorporated into the student and instructor stations: motion, visual, electronic warfare, voice masking, automated instruction, and a host of other goodies. As part of a building block approach, additional sophisticated technologies will be incorporated within the next 10 years.

Still, the pilots avoid the facility like the plague. Getting into the simulator ranks in the desired activity list somewhere just below child support, alimony, and knee surgery. Having a session in the simulator is something pilots avoid if possible and don't admit to if forced to.

How can this be? Five years and $100,000,000 has been spent to develop, produce and field this simulator. The best minds of the developers, producers and users have supposedly been put together in the effort to bring these simulators to use.

It really seems that something's incongruent has happened. I remember my first experiences with simulators with a great fondness and respect. I had a little simulator time during pilot training, but my first real experience was in my first assignment flying Aeromedical Evacuation in the C-131 (Convair 240, T-29).

As I understood it then, the simulator had been built in the early fifties and was condemned in the late fifties. We were using it in the late sixties because it was the only one that had ever been produced and we had to have something. To make matters worse it was designed for the Convair 240. The Convair 240 and the nine models of the T-29 and C-131 were basically the same aircraft. However, there were just enough differences (primarily in the electrical system) to make trying to teach all models in the same simulator an interesting experience at best. Talk about "this doesn't really fly like the airplane": This simulator made nonfidelity an art form!

It's worth a few minutes to digress and describe this simulator. It had what I would call a first generation visual system: frosted windows with a rheostat to turn the lights up and down. This way you could simulate flying in clouds (lights down), heavy clouds (lights further down), thunderstorms (lights off), lightning (lights off with strobe lights going on and off), no clouds (lights full on), or breaking through a ragged cloud layer (lights on and off). As an added bonus there was a visual check for an engine fire. If there was a "real" fire, as opposed to faulty instrument indications, the instructor could turn on a red Christmas tree light that flashed just outside the side frosted window of the engine on fire. Eat your heart out visual engineers!

This simulator was not lacking in aural cues either. The engine sound track resembled one of those World War II movies when 300 B-17's are flying over Potsdam. Changes in power were merely reflected by changes in volume. The crash noise was a classic. I'm just sure it originated from an Abbot and Costello movie. About the only thing it needed to complete the vaudeville image was a scream at the end and the sound of one breaking glass. My favorite aural cue was ice on the propellers. Now it's tough to see ice on the propellers even in the airplane. Your only clue is usually the sound of the ice shedding and hitting the fuselage. In the simulator this was simulated with a small axle parallel to the outside of the simulator. Attached to the axle were varying lengths of spring wire with various size steel balls at the ends. As the axle rotated the balls would spring back and hit the fuselage at irregular intervals. I never had real prop ice, but I was sure, that if I ever did, it would sound just like that.

simulator was ahead of its time. That was in the area of nasal cues. I have seen simulators that people said "stunk", but, to this day I have yet to see a simulator with nasal cues. This particular feature was one of my favorites, and it was used in conjunction with simulating an electrical fire. No fancy keyboards or CRTs existed to input this emergency. The procedure was for an instructor to take a piece of insulated wire (provided) and clamp it between two terminals next to the intake duct for the cockpit air conditioning system. Current was then applied to the terminals and the resulting short circuit burned the insulation off the wire. The inevitable smoke flowed into the cockpit with the trainees. Now that's imagination and realism all rolled up into one. Which brings up the subject of the instructor station...

The instructor station was really something. As I said before no fancy keyboards or CRTs existed. Neither was there auto demo, graded maneuvers or programmed emergencies. The instructor had before him approximately 500 marked swithches and rheostats on an electrical panel. Typically he was busier in the back than the guys up front controlling each maneuver and malfunction with a number of individual controls.

What about fidelity? Now there's a laugh. The simulator compared to the Convair like a Porsche does to a Peterbilt. You fought the simulator all the time. Talk about overcontrol; that's what you did in the simulator. Holding a heading was like balancing on a beach ball. All nine models of the T-29 and C-131 were taught in the simulator so the instrument panel wasn't correct for anyone. The electrical system in the Convair was the most crucial and the most difficult system to learn. In addition, the simulator didn't have all the instruments in the right place for any of the models. Talk about antiquity and negative state of the art! It was all there in our simulator.

What you may be expecting to hear is how much we hated the simulator, and, with all the improvements since then, why there isn't any reason pilots should feel the way they do about simulators. Actually what I'd like to say is that we loved it and there are some very good reasons why pilots are not killing themselves for the opportunity to fly simulators.

The Convair simulator was great! I always looked forward to a week at the simulator; even twice a year; even on my tenth trip. Why? Because I learned something and what I learned was meaningful. Well you ask, what was so wonderful about that particular simulator?

It had a number of things going for it that more than compensated for the lack of technology. Many of these things are not present in our simulator programs today. First, the emphasis was that the simulator was part of the training program. Now this may seem obvious, but in many cases it is not. Our week at Scott was not one simulator ride after another. The simulator was merely a tool used in a refresher course which emphasized system operation and emergency procedures. Simulator rides were used to demonstrate principles learned in class, emphasize systems lessons, demonstrate malfunctions and give the pilot a chance to practice what he had learned. <u>The simulator was not the training program.</u>

training program, there was no attempt to teach everything in it. If the simulator did not have the capability to enable training a particular maneuver there were not any squares to fill to show that we tried.

Third, the simulator was used to make what flying time we did have more effective. Even in 1967, flying time was not in abundance. What limited training time we had was valuable. We used the time in the simulator to train to a level commensurate with the simulator's capabilities. It was never considered that we would use simulator time to replace flying time. We needed the simulator time to make our flying time more meaningful, productive, and safe.

Fourth, and this goes along with two and three, we didn't worry about "fidelity" as an end. The important thing was the ability to train a particular maneuver effectively. Sure, it handled poorly, but it was understood that, if we could fly the simulator and handle emergency and instrument procedures, the real thing would be a breeze. From experience I can tell you that this was true.

Fifth, and probably most important was the ability and attitude of the instructors. Teaching in the simulator was not rotated among whomever could be conned into teaching in the simulator. The simulator instructor position was a truly selective position and individuals who were assigned to the position were the ones who had the inside track for good report cards and promotions. As a result, we rarely lacked quality instruction. The instructors were professional, knowledgable and excellent teachers. This made a real difference. As a testimony to the quality of this program, the simulator was given much of the credit for over 500,000 accident-free flying hours that the 375th Aeromedical Airlift Wing enjoyed operating 20-year old aircraft. When the aircraft were retired in the early seventies, their accident-free record remained untarnished.

So what's the point? What can we learn from this experience? For years we've been meeting like this and telling each other what wonderful things we're doing, have done, and hope to do in the future for the simulator world. In the process, we've looked at the pilot "through a microscope." We've analyzed him, scrutinized him, and studied him. We've studied his aircraft, his mission and his bodily functions. We've made great strides in technology, digitized computers, expanded fields of view, increased resolution and focussed on fidelity. Our reward for all our work has been a pilot who would much rather play "pac-man" than train in our $10-$100 million electronic training devices. Have we done something wrong? If so, where have we gone wrong? How can we do it better? Certainly with the quality of our equipment our programs should be able to easily exceed the effectiveness of earlier programs like Air Evac's. To me the problems are observable, predictable, and correctable...but not easily.

These problems are tied up in four words:

1. Overestimate
2. Underanticipate
3. Overemphasize
4. Overcomplicate

There isn't any one sector that can be identified as the guilty party. <u>Everyone</u>, yes everyone, has had a part. These include developers, the contractors, acquisition agencies, the Pentagon, command headquarters, testing agencies, requirements people, and...yes...the pilots themselves.

The first word is overestimate, specifically the simulator's capability to meet all our needs in a certain limited time. To me this tendency started with the oil embargo in 1973. Ever noticed how fashionable it is these days to trace all our problems back to the Arab oil embargo. Anyway, up until then, simulators had been going along fine in their proper role and gaining in capability. Then someone got the bright idea that we could use simulators to replace flying time rather than just increasing the effectiveness of it. Therefore the more we used simulators the less we needed airplanes and the more we could save gas. The conclusion was that simulators were pretty good but many dreamed that with some good old American ingenuity simulators could be developed so that pilots would never have to leave the ground...except in an emergency, of course.

This led to a flurry of technological efforts and flight hour tradeoff studies. Some elements of the Air Force committed themselves to giving up flight hours in exchange for a certain simulator capability. These estimates were based on projections of the expected technological advances. Unfortunately the technology was not all that was expected as soon as expected. Furthermore the estimates had been fudged a little to make the case look better because surely they wouldn't take away all that flying time.

Now consider the pilot. He knew instinctively that he could not minimize his flight time to the extent that his proficiency deteriorated. But everyone said "Trust me, you'll really be impressed with its capability. Reluctantly, he said "OK".

Five years later the simulator arrives. It's two years late and the flying hour cuts have taken place two years earlier. Unfortunately the costs of the full visual capability have escalated and it's been cut from the program. Besides there wasn't enough spare memory in the computers to handle the visual system. Also the flying qualities aren't the same as the airplane because the simulator was built on design data, and flight data wasn't available until after the critical design review. That was four years ago but the program couldn't afford the cost growth that would be required to use flight test data. Or we have the flight test data but it doesn't have enough data points or our sampling rate needs to be larger or any number of a myriad of technical reasons why it isn't quite right or wasn't delivered on time. The base newspaper has an article about the simulator and says that it has just passed its reliability testing with flying colors. However, one-half hour into the first mission it has five computer halts. These are explained as merely software "gliches" that were not reflected in the reliability data because software does not fail. I could go on and on, but why beat a dead horse. Simply classify it under the first word: We overestimated what we could do.

The second word is underanticipate. It could also be three words: lack of planning. It seems in the last few years many simulators arrive on base just about the same time as the training syllabus. One of the neat things about the Air Evac simulator was that it was part of the ground training program. It's obvious that the training program should be conceptualized and then it should be determined where a simulator or other training device could be used to effectively train what has to be trained. Trainer features seem to be obtained like someone in the grocery store without a list: whatever sounds good is what we order. There seems to be minimal thought placed in (1) developing a syllabus, and (2) requesting those features which will best fit in with that syllabus.

Overemphsize is the third word and fidelity is the one that goes along with it. Simulation is exactly that: simulation. By definition, no simulator will ever have total fidelity. Furthermore, total fidelity doesn't guarantee an excellent training device. The real airplane has complete fidelity, but is only an excellent training device with a competent instructor. The Air Evac simulator had very little "fidelity", but the way it was used made it an extremely capable training device with a great deal of training capability. Our preoccupation with "fidelity" has driven up the cost and complexity of simulators and detracted from their training capability.

Consider the pilot in the field again. He hears everyone talking about fidelity. Therefore, when he goes to the simulator he's looking for something to be not quite like the aircraft. He doesn't have to look far, and, no matter how much money we spend, he will always be able to find things that are not quite like the aircraft. And, if all we're concerned about is fidelity, we can certainly get that much cheaper and quicker in the aircraft. Rather we should talk training capability. That's what we're after, isn't it? And, it should be training capability for those portions of the mission for which the simulator is best suited and designed.

The last word is overcomplicate, and it's really a synthesis of the other three. Our preoccupation with fidelity leads to expensive systems that are difficult to maintain and costly to operate. Furthermore we deemphasize training capability. Our failure to design the training program in advance of the simulator leads to the "give me everything there is and we're bound to build an effective training program" approach. The problem is that it's always too expensive, something always gets cut, and there is no way to evaluate what is most important because there isn't any training program with which to compare it. A good example is that many of the instructor stations have many expensive, underutilized systems. Had there been a development of the training program first these could have been identified as unnecessary and the funds diverted to other more valuable features.

Well, those are the problems as I see them. And it has been said many times that anyone can be a critic. What do you do to make it better? The first recommendation is, of course, to design the training program first. The simulator should then be appropriately integrated into the training program. This is not new advice, but it still holds true. With this kind of approach you can take a look at the tasks you need to train most and let the developer work to obtain that capability. This also precludes the tendency to ask for the moon.

Secondly, be realistic with schedules. The acquisition agency puts out a request for delivery of a simulator in three years, knowing this is an unattainable goal. The rationale for this procedure is based on deliveries being historically late. The contractor, to ensure contract award concurs with this schedule.

Don't forget the software, documentation and spare parts. As a pilot I must admit these are three fuzzy-wuzzy areas in my mind except when the simulator doesn't work, breaks down and can't be fixed. Mumbo-jumbo about the reliability figures do not consider software failures as failures, the level of documentation that we ordered doesn't cover this, and "this part has 'downed' the simulator but we won't be able to get it for six months" doesn't build confidence in the capability of these devices.

The last one is probably the toughest one and the key to the whole program: obtaining good, motivated, exceptional instructors. This involves changing an entire attitude about simulators. In many cases, simulator programs have become the dumping ground for passovers. And if they're not passovers when they get there, they are soon after because they are not recognized for their contributions.

Simulators have considerable capabilities. They can enhance and improve any training program. The important thing to remember is they cannot replace an airplane, or enhance a poorly conceived and executed training program. Thank you.

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THE USER'S ROLE IN MAJOR TRAINING SYSTEM ACQUISITIONS - AS PERCEIVED BY THE DEVELOPER

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ABSTRACT

The purpose of this paper is to delineate the various responsibilities and interrelationships of the agencies involved in the acquisition of a major training system. ~~As the title suggests,~~ this paper will emphasize the role of the user as perceived by the materiel developer. Discussed within the paper will be these interrelationships as they exist with a major Army training system acquisition. The participants will be identified, the four phases of the acquisition process will be presented and a discussion of the role of the user in this process will be highlighted. Also covered will be the user's role in the development of Front-End Analysis (FEA) materiels and Task and Skills Analysis (TASA) documentation. In addition, a common vocabulary will be included to establish a basis of understanding and suggestions will be offered on problems which need heightened interest and tracking during the design, development and acquisition processes.

INTRODUCTION

In Army training system development, there are primarily four groups or agents who play a critical role. These include the materiel developer, the training developer, the user school (or proponent) and the selected contractor who will produce the training system or device. Although there are numerous other agencies and participants in the entire training system acquisition cycle, for the needs of this paper, only these four critical participants will be addressed. Once identified, the role of these agencies will be matched to the acquisition process itself. Focusing on the user proponent and its role in the process, suggestions will be offered as to how a more productive relationship between agencies may be obtained. The user's role in the development of FEA and TASA materiels will also be addressed.

ACQUISITION CYCLE PARTICIPANTS

A description of the four participants identified as critical for this discussion can be found in the PM-TRADE Training Device Acquisition and Life Cycle Management Guide as prepared for the Project Manager Training Devices, U.S. Army.(7) For the purposes of this paper, these participants are the Training Developer, Materiel Developer, Proponent School (User) and selected contractor who will develop the training system or device.

The Training Developer is that agency responsible for the formulation of training concepts, doctrine, organization, training objectives and requirements for the training of U.S. Army Forces. This command or agency is responsible for the development and conduct of training which will provide the skills necessary to operate and logistically support materiel systems being developed. In most instances, the principal Training Developer is the U. S. Army Training and Doctrine Command (TRADOC).

The Materiel Developer is the element responsible for research, development, production and production validation of a training device. In most cases, the Project Manager for Training Devices is the principal Materiel Developer. The Project Manager (PM) of the systems involved (e.g., M-1 Tank, U.S. Roland, Firefinder, AH-64) is generally charged to oversee the total project and provide funding. Working with and within this agency is the Project Director at PM-TRADE who is assisted by the Naval Training Equipment Center. The responsibility here is to turn a proponent school's (user's) training requirements into specifications for inclusion in a Request for Proposal (RFP). This is the document that provides a description of the items to be procured. It is a request for a manufacturer to submit a proposal supported by a cost breakdown. By directing this effort, the Project Director is considered the driving force for PM-TRADE in the accomplishment of the mission of training device acquisition.

The User (or proponent school) is designated as the command, organization, or unit that is to receive the training system or device from production for use in accomplishing a designated mission. The user provides guidance to the materiel and training developers during the training device acquisition process on matters pertaining to the expected operational employment and logistic support. Although not always, the user or proponent is normally the agency who supplies to HQ TRADOC a training device requirement for validation. This validation process encompasses the establishment of a Joint Working Group consisting of representatives of PM-TRADE, USATSC (U.S. Army Training Support Center - the training device focal point for TRADOC), and the Proponent School (Armor, Infantry, Air Defense, Artillery, etc.) with the DARCOM-PM (Dept. Army Readiness Command-Project Manager). It is the Training Device Requirement (TDR) document prepared by TRADOC which gives operational, technical, and cost information necessary to obtain Headquarters, Department of the Army (HQDA) approval. When approved by HQDA, the TDR is the document of record of the Army's requirement and will contain the guiding factors against which developers and contractors meet the user's needs.

The selected contractor is an individual, partnership, company, corporation or association having a contract with the procuring activity (usually PM-TRADE with the contracting auspices of Naval Training Equipment Center) for the design, development, manufacture, maintenance modification, or supply of items under the terms of a contract. In the case of a training device, this participant builds the hardware and develops the training scenarios and software as per the specification requirements of the contract. This is the legal agreement between the Government and Industry for the acquisition of the device needed.

Within this paper, these four participants will be of concern with the user's role highlighted, in particular with respect to the training device acquisition process.

TRAINING DEVICE ACQUISITION PROCESS

The training device acquisition process consists of four distinct phases. They include (1) Need Identification - Concept Formulation Phase, (2) Demonstration and Validation Phase, (3) Full-Scale Engineering Development Phase, and (4 Production and Deployment Phase.

The Need Identification - Concept Formulation Phase is where training voids, new training needs, and technological forecasts are identified by the Training Developer to determine the training capabilities, doctrine, organization, or potential training devices that will improve the training of the Army. The Demonstration and Validation Phase is where technical concepts are validated to determine if they fulfill the needs or voids that were identified and that training effectiveness is achievable. In the third phase, Full-Scale Engineering Development Phase, the training device or system is fully developed, engineered, fabricated, tested and a decision is made whether the item or system is acceptable to meet the requirement. In the fourth and final phase, Production and Deployment Phase, the training system or device is procured and distributed, individuals or groups are trained in its use, and logistic support is provided. Within these phases, normally the procurement and contract administrative services are provided by, or through, the Contracting Officer from the Naval Training Equipment Center, Orlando, Florida.

LINES OF RESPONSIBILITY

After examining the participants and the process of training device acquisition, it would be helpful to discuss the working relationships involved. Establishing clear lines of responsibility and coordination, plus review and guidance channels among the participants in the acquisition process is difficult at best. The system for achieving this coordination is theoretically in place, but more often than not during the acquisition of a major training system or device, many of the participants at one time or another are "overtaken by events" and these channels inevitably break down. This breakdown can be caused by a number of reasons - it could be simply a lack of communication and/or the inability to establish clearly defined lines of participants in the acquisition process is one that requires dedicated coordination and clearly defined areas of responsibility to ensure timely and accurate input into training requirements and the resultant training system or device development needed to fulfill these needs. A breakdown between developer and user; between developer and contractor or any combination of participants, could result in an inadequate or inappropriate development product.

THE USER'S ROLE

The user's (or proponent school's) involvement in the acquisition process should be one of active participation from the early stages of requirements definition and TDR development up through and beyond the actual design, development, acquisition and delivery of the training system or device. The user's role begins with the initial identification of a training need. At this point a complete FEA should be conducted by the proponent to determine how the training system or device would fit into the total training program. This analysis addresses the how, who, when, why and where aspects of the proposed utilization of the training system or device.(6) Because the Army is committed to the "Systems Approach" for the development and acquisition of major materiel items,(4) it is mandatory that the user be versed in the Instructional Systems Development (ISD) process and be able to work confortably within its guidelines. Front-end analysis as part of the ISD process has been described as the "interactive process by means of which the requirements of a system may be progressively more definitive and brought more sharply into focus."(5) This implies that FEA is an on-going and dynamic process that requires the authors to up-date and "fine tune" the information presented as the knowledge base about training requirements and needs expand. In most cases, part of this requirement analysis will include Task and Skills Analysis (TASA) of a present or nearly deployed weapon system for use in the development of a required training device. This Task Analysis will not only serve as a basis for the Training Device Requirement (TDR) but could conceiveably be part of a government deliverable to the contractor to form a baseline from which to work. It is because of the fact that the acquisition process embraces all phases from inception of a training need to completion of a contract(2) that the quality of the front-end input is so important in the success of developing a needs responsive device or training system. Central to this idea of quality input, is the associated need of continued input and communication between user and materiel developer throughout the acquisition cycle. This is most critical when the materiel developer is monitoring and reviewing the work of the contractor. As an example, after contract award and during actual development of a training device, problems sometimes arise concerning the exact definition or training intent for the device that is to be procured, or possibly a change in training needs has developed. The quality of communication and input that takes place between the materiel developer and user can determine the effectiveness and useability for the training device when delivered. A lack of quality input or a lack of timely input can both result in inappropriate training design and can slow the development process, possibly causing additional expense. As mentioned before, clarification of user need is dynamic and always improving in terms of precision and accuracy of training requirements. Certainly, the user can be instrumental in helping the materiel developer make critical decisions on such items as; which task to train, review of instructor display formats on training devices and the requirements for student performance records, to name just a few.(1) The addition of this requirement to the school's list of responsibilities - platform instruction, training extension courses, field manual development, and training device requirements development, etc.(3) is indeed a tall order, but one that will pay dividends in the form of increased training effectiveness of the devices being developed. The better the quality and timeliness of the school's input to the materiel developer during this stage of the acquisition process, the better the quality of the device itself.

SUGGESTIONS FOR IMPROVEMENT

If the user schools are to provide the needed input to the acquisition cycle in both a quality and timely fashion, it is necessary that they be supplied with the needed resources and personnel to do the job correctly. It is important that the members of the acquisition team do not have their abilities and energies stretched too thin. Subject matter experts, tacticians, instructors and instructional system developers are needed to supply the required information. Those individuals assigned the responsibility for these areas must also use their role as decision-makers. Their opinions and direction are required to help improve this training device acquisition cycle. When these qualities are lacking, the materiel developer and others involved in the acquisition process are left to their own devices to secure the appropriate answers. A deferred user decision is a decision someone else will make. The user will be ultimately required to live with this decision.

A second improvement could be made if a better system of "corporate memory" were instituted within the schools. This might be achieved by maintaining a more stable cadre of individuals who can stay with a project from inception to completion. This would help solve the "learning curve problem" and "memory loss" associated with a high turnover of personnel. Working with the materiel developer and all members of the acquisition process, the user must keep abreast of program direction and maintain a steady flow of input. This will assure that the school's views and needs are kept in the forefront. To do this effectively, it is mandatory that the "corporate memory" of the school be maintained and when personnel changes are required, a conserted effort is made to bring the new member up to speed, and to enable him to become a productive, contributive segment of the team.

A final suggestion would be the improvement of the communications link between the materiel developer and the user school. All too often vital information needed for the steady progression of the acquisition cycle "finds the cracks and falls through" for lack of an efficient communications link. Establishing a more efficient communications network between the developer and user could go a long way in improving the reception and use of the delivered materiels. It must be stressed that the responsibility of seeing that this communication link exists is as much the school's responsibility as it is the materiel developer's. In fact, it is in the school's or user's best interest to keep this link connected and used to its fullest benefit. When the user keeps the developer informed and up-to-date as to what the user's needs are, everyone benefits.

CONCLUSIONS

The user's role in major training system acquisition from the perspective of the materiel developer is one of active participation from the early stages of requirements definition to delivery of the training system. Quality and timely input at all required stages of the process will pay returns in the form of a training effective product. In this respect, it is vitally important that the user assume a leadership role in providing the necessary information concerning FEA and TASA materiels needed to develop an effective system, and continue this role consistently throughout the entire process of training needs identification, design, development and acquisition of the system involved. Given the expertise, dedication and ability of the personnel at the user schools, it is imperative that an effective communications link be established between developer and school to tap this invaluable resource and use it to its best advantage during the training system acquisition process.

GLOSSARY

The list included here is intended to help establish a common base of definition of some of the terms used throughout the acquisition cycle. Although not all inclusive, this list includes many of the terms used in this paper.

Acquisition Life Cycle. Normally consists of four phases (Concepts, Validation, Full-Scale Engineering Development, and the Production and Deployment) with key decision points reached at program initiation and between each of the phases for major systems. These phases explain a normal acquisition path, not a prescribed path, which all programs must follow. A program may skip a phase, have program elements in any or all phases, or have multiple decision points per phase

Materiel Developer (MD). The command or agency responsible for research, development and production validation of a system (to include the system for its logistic support) which responds to HQ DA objectives and requirements. Materiel developers designated from the following, with specific responsibilities assigned as appropriate: Chief of Engineers, The Surgeon General; CG DARCOM, CG USACSC; CG USAINSCOM; and CO, U.S. Army Research Institute (ARI).

Product Manager (PM). The individual, designated by a Materiel Developer, who is delegated authority and assigned responsibility for centralized management of a particular development/acquisition or other specified program that does not qualify for system/program project management but requires some degree of centralized management.

Project Manager (PM). An individual, chartered by the CG, DARCOM, who is assigned the responsibility and is delegated the full-line authority for the centralized management of a specified development/acquisition project.

Proponent School. The TRADOC school designated by the CG, TRADOC, to exercise supervisory management of all combat/training development aspects of a materiel system.

Request for Proposal (RFP). Request for the manufacturer to submit a proposal supported by a cost breakdown. It provides a description of the items to be procured. It may include specifications, quantities, time and place of delivery, method of shipment, packaging and instruction manual requirements, materiel to be furnished, and data requirements, both logistic and administrative.

Training Developer. The command or agency responsible for the development and conduct of the training which will provide the skills necessary to operate and logistically support materiel systems being developed or otherwise acquired. (For most equipment, this is TRADOC).

Training Device. Any three-dimensional object developed, fabricated or procured specifically for improving the learning process. Training devices may be either system devices or non-system devices. Items which simulate or demonstrate the function of equipment or system such as three-dimensional models, mockups, or exhibits, and are designed, developed, and procured solely to meet training support requirements. They are further defined as follows:

(a) System devices are designed for use with one system or item of equipment, including subassemblies and components; e.g., launch effects simulator for the TOW missile system and Shillelagh Conduct of Fire Trainer (COFT) for the M551, etc.

(b) Non-system devices are designed to support general military training and/or for use with more than one system or item of equipment, including subassemblies and components; e.g., Multiple Integrated Laser Engagement System, etc.

Training Device Acquisition Process. A sequence of specified decision events and phases of activity directed to achievement of established program objectives in the acquisition of training devices and extending from approval of a training need through successful deployment of the system or termination of the program.

Training Device Requirement (TDR). A document prepared by TRADOC with the assistance of PM-TRADE which gives operational, technical, and cost information necessary to obtain HQ DA approval. When approved by HQ DA, the TDR is the document of record of the Army's requirement and will contain the guiding factors against which developers and contractors meet the user's needs. A HQ DA-approved TDR supports the expenditure of RDTE and/or OPA funds for development and/or procurement of the training device.

User. The command, organization, or unit designated to receive the training device from production for use in accomplishing a designated mission. The system is included in the user's TOE, TDA, or in an appropriate Common Table of Allowances (CTA). The user provides guidance to materiel and training developers during the training device acquisition process on matters pertaining to the expected operational employment and logistic support.

NOTE: These and other definitions which are useful in understanding the acquisition process and the role each participating agency plays in its completion, can be found in the Training Device Acquisition Management Model (TDAMM), prepared for the Project Manager Training Devices, United States Army.

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SAVE OUR SIMULATORS (SOS): A DISTRESS CALL FROM AN OPERATIONAL USER

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ABSTRACT

This paper discusses some of the problems experienced by operational users in their efforts to obtain maximum training benefit from Advanced Flight Simulators. The major shortcomings of simulation training identified here are not the result of state-of-the-art technology limitations. In fact, many of the training difficulties encountered by simulator users today may have been avoided if greater attention had been given to defining Mission and Task Requirements during simulator design. This suggested emphasis on Mission indicates a change of mind-set is needed that focuses on explicit operational requirements as well as the more conventional technical approach. After analysis of typical simulator training problems, it is concluded that simulation training could benefit substantially through greater consideration to front-end analysis during simulator design, and by providing training personnel with well designed instructional programs that includes an objective Performance Measurement System.

INTRODUCTION

Training aircrews in such complex tactical mission areas as Air Combat Maneuvering (ACM) has always been difficult at best. This is largely because of the dynamics and complexity of these mission environments: Multiple interrelationships among numerous systems must be perceived and managed, plus the need, during critical phases, to process substantial information and respond to manifold task requirements.

Until recently, this "higher order" training was only possible during actual aircraft operations, with the built-in limitation of not being able to adequately interject sophisticated threat systems into specific training missions, as well as the lack of a means to repeatedly practice complex mission tasks.

Background and Discussion

Simulators have been around for quite some time, and most of us (military aircrews) have learned to fly utilizing a certain amount of synthetic flight training. They have until very recently been designed primarily for instruction in such areas as:

- Standard Operating Procedures (SOP)
- Emergency and Irregularity Procedures
- Instrument Flight Procedures
- Weapons System Operational Procedures.

Procedures oriented training was, therefore, about as much as we could expect from available simulation design capability.

However, the near revolution in computer technology has changed this.

Driven largely by advancements in informational display technologies, simulators are now capable of providing for "Higher-order" mission related training previously not possible.

In view of such advances we would assume that operational training personnel would be welcoming these devices with open arms. Unfortunately, this is not the case. Indeed, many 'customers' of these advanced training devices hold them in low esteem. But, why is this so? What exactly is the problem? And what, if anything, can be done to improve this low customer acceptability?

"Various significant problems in operating this air combat simulator have become manifest. Among these include: inadequate implementation of instructional design features; poor design of the operation (features) of demo and debrief equipment and procedures . . . .and demonstration creation process lengthy and difficult to perform."(1)

The above statement was extracted from a formal qualitative review of a recently introduced Full Mission Flight Simulator designed to support Navy fighter training. A close look at these and other similar problems reveals that (1) they are endemic to the recently introduced class of advanced flight simulators designed to instruct in complex mission areas, and (2) these problems are largely operational, vice technical in nature.

In addressing these "operational" difficulties, this paper attempts to pinpoint significant problem areas and their underlying causal factors which are resulting in low customer acceptability. Additionally, a new conceptual approach for viewing advanced simulation systems is suggested, as well as a discussion of the possible application of this conceptual framework in subsequent design and/or modifications to these sophisticated training systems.

It should be emphasized that it is not the intention of this treatment of simulation design to single out and criticize any individual group or place anyone in bad light. By candidly discussing certain operational difficulties and suggesting a possible course of action it is hoped that a dialogue can be established between operational users and the siumlator design community in order to improve overall mission performance of these important training systems.

Problem Statement

While it was orginally believed that most simulator shortcomings were either the result of technological limitations or to a lesser extent funding constraints, a recent problem analysis conducted by the author revealed that many major systems deficiencies fall substantially outside these categories. Our major difficulties, it seems, do not stem from these areas - our technology is maturing nicely and considerable funding appears to be available for adequate design - but stems largely from the absence of a coherent "mission logic" to drive the cognizant simulator design. Moreover, since this conventional design process usually commences with design specifications which remain largely technical, inadequate focus is provided for many critical mission requirements. Consequently, important mission considerations during the conceptual design phase are either superficially addressed or totally ignored.

A comprehensive analysis of simulator problems brought to light the following fundamental areas where significant efforts should be directed.

- A change of mind-set appears to be needed to move from an exclusive technical focus to a broader view which fully embraces mission requirements and instructional design requirements as well.
- A mechanism is needed to spotlight critical mission areas, thereby bringing to bear appropriate resources so that enhanced training can be conducted to improve performance in these critical regions.

Although many of our advanced full mission simulators are experiencing certain technical difficulties, most of these are either being corrected or corrective action is being contemplated. On the other hand, the difficulty of many of these same devices to adequately instruct in important mission areas for which they are designed, poses a more serious problem because it strikes at the very heart of the conventional design process. For example, a recently installed full mission flight simulator for West Coast Navy fighter training exhibits the following "mission related" deficiencies which, it appears, should have been addressed during the original design process.(2)

Mission Area	Deficiency
One vs. One Tactics (1vs1)	o Only two models used for Wide Angle Visual (WAVS) presentation. Need additional aircraft models to simulate full threat spectrum.
Missile Envelope	o Air-to-air threat missiles are not simulated. Need reasonable inventory of threat missile systems.
Missile	o Missile firing light source lacks accurate fidelity. Need improved visual presentation.
SAM Defense	o SAM does not fly profile. Also need an expanded inventory of "real world" SAM threat systems.
Advanced ACM Tactics	o Capable of only 1vs1. Need expanded capability to include 1vs2, 2vs1 at minimum.
Low Altitude ACM	Inadequate ground growth. Need visual method to determine altitude in simulation of 'real world' conditions.
Overland ACM	o System is locked into an overwater mode. Need both land and water.
Basic Problem Scenarios	o System unable to run desired scenarios due to unreliability and inadequate design attention to this area.
	o System record feature limited to 1 hour. 3-hour minimum needed to cover all desired scenarios.
Engagement Geometry Analysis	o Threat bogey cannot be scenarioized (directed) to demonstrate classical adversary maneuvers. Need capability to provide this important training requirement
Sortie Debrief	o System employs wholly inadequate performance measurement system.

A somewhat different system also utilized for fighter tactics training exhibits similar shortcomings:(1)

- Inadequate instructional design features. Demo and debrief systems inadequately designed and difficult to use.

o Adaptive maneuver logic (of threat aircraft) varies in performance.

o Demo create process involves a lengthy procedure and is thus difficult to perform.

o Debrief printouts difficult to understand and of limited usefulness.

It appears from the foregoing that although technology plays a part, a significant number of identified problems clearly reside in the category of "insufficiently defined mission and training requirements."

STRUCTURED APPROACH TO FORMULATING SIMULATOR DESIGN CRITERIA

The means of translating appropriate "mission logic" into full mission simulator design features suffers from a clear, well defined process. The need, for instance, of having an unambiguous and comprehensive understanding of the cognizant mission prior to addressing conceptual design options is self-evident. While it would be naive to suggest that design teams do not design with the overall mission in mind, experience has shown that these same teams are not provided with, and thus do not adequately address, critical mission requirements as part of the conceptual design process. Approaches have been utilized in the past to attempt to understand and document mission driven training requirements, yet an acceptable methodology unfortunately is not evident. (The ISD model is a movement in this direction but significant shortcomings exist for many purposes beyond curriculum development, due to its inability to adequately analyze the cognizant mission: Most of the methodology is directed to specifying tasks and behaviors.) One possible method, suggested here, is presented in the interest of stimulating dialogue with a goal of eventually establishing a structured approach to advanced simulator design. This proposed scheme, presented in the broadest of brush strokes, follows a straightforward logic process outlined below (and graphically displayed in Figure 1). A more detailed description of each element of the scheme follows in subsequent paragraphs.

<u>Structured Approach to Simulation Design</u>

o Conduct a formal <u>Mission Analysis</u>, structuring the mission to include functional sequencing, scenarios, task requirements and performance objectives.

o Perform an <u>Instructional System Requirements Analysis</u> in order to select appropriate instructional methods for selected mission objectives.

o Utilizing a systematic approach,

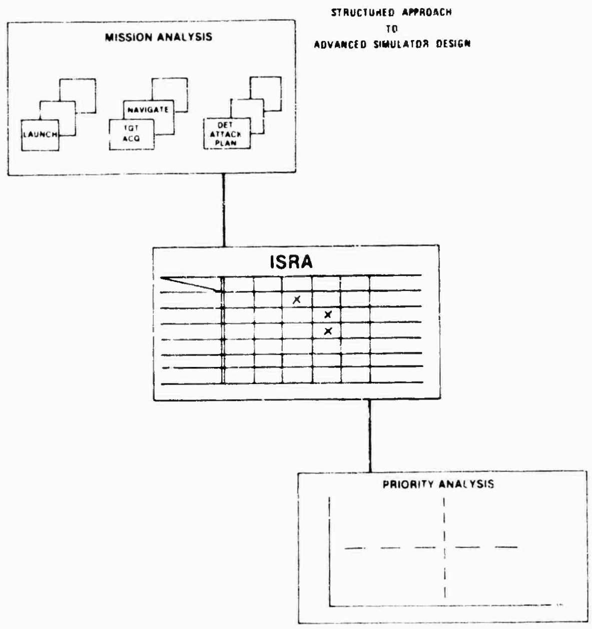

Figure 1

conduct a <u>Priority Analysis</u> by assigning priorities to specific mission and operator task areas; spotlighting candidate simulation design features which will realize the greatest training payoff.

<u>Mission Analysis</u>

A selected operational mission is formally analyzed by following the logic process depicted in Figure 2. Although space does not permit a detailed examination of the methodology, the following outlines the important steps.

o The process of analyzing a cognizant military mission commences with a coherent - albeit generic - mission statement. A mission statement describes, in broad terms, the purpose of a warfare-specific operation.

o Functional mission hierarchies are constructed next to identify mission elements, specifying broad mission tasks, and depicting relationships.

o Overall mission objectives are then specified for appropriate mission elements identified in the step above. Objectives are needed to understand broad performance requirements of the scrutinized mission.

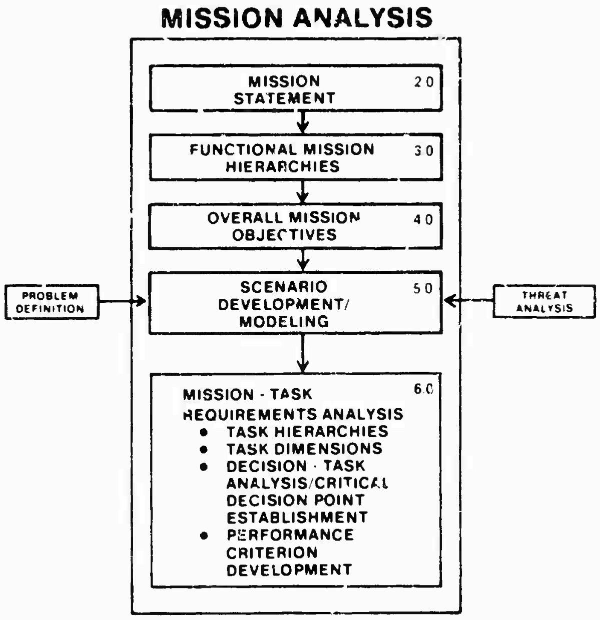

Figure 2

o Scenarios are developed to explore threat-imposed constraints, mission profiles, tactics, critical mission segments and broad resource needs to successfully carry out the intended operation. Functional sequencing, scenario tree analysis, and P_K (Probability of Kill) equations are the three common analytical techniques utilized in this step.

o Mission-task requirements, the last step in the process, constructs task hierarchies, specifies task dimensions, identifies critical decision points and relative task loading, and suggests task performance criteria in an attempt to fully understand detailed requirements of the mission.

Instructional System Requirements Analysis

An analysis of training requirements driven by the previously outlined technique for analyzing the mission, is designed to specify appropriate training tracks and training objectives and relate these to candidate training methods. A convenient means to conduct this analysis is to create a matrix as shown in Figure 3. As indicated, this rather straightforward analytical technique specifies mission objectives (derived from the aforementioned mission analysis) on the horizontal axis vs. candidate training methods along the vertical axis. Note the ACM portion of the fighter mission, selected for this example, is decomposed to a level sufficient for analysis and is arranged in a systematic sequence. Finally, for each mission objective, candidate methods of training are identified by X-ing in appropriate boxes. For this paper we are concerned primarily with simulation, although this technique, being generic, appears to be suitable for a wide range of instructional needs.

Priority Analysis

After candidate training methods are identified, determining candidate design areas based upon the examination of critical mission requirements is considered the next logical step. This suggested process or methodology is outlined below.

o Select an appropriate mission objective (or phase) where simulator training is suggested from the aforementioned matrix.

o Determine relative importance of this mission phase utilizing expert interviews and conventional scaling techniques (a one-to-ten scale appears appropriate).

o Decompose selected mission phase into its component tasks (task hierarchy).

o Arrange related tasks into groups or modules.

o Examine overall difficulty of these task modules by determining aircrew task loading during this phase of the mission as follows:*

-Tasks performed individually in sequence - low rating (1-3)

-Multiple tasks performed simultaneously under relaxed time conditions - medium rating (4-6)

-Multiple tasks performed simultaneously under increased time compression - high rating (7-10)

o Plot mission importance vs task difficulty on conventional graph as shown in Figure 4.

o Superimpose demarcation lines on the graph forming four equal quadrants.

Mission objective/task modules plots which fall in the upper right quadrant represent the highest priority areas where design efforts should be focused and where maximum

*The previous mission analysis, having identified critical decision points and task loading will aid this analysis considerably.

INSTRUCTIONAL SYSTEMS REQUIREMENTS ANALYSIS MATRIX

MISSION OBJECTIVES (ACM) / CANDIDATE TRAINING METHODS	TARGET ACQUISITION			EVALUATE TACTICAL SITUATION			MANEUVER AGAINST THREAT				NEUTRALIZE THREAT	
	ESTABLISH EFFECTIVE RADAR PROCEDURES	ACQUIRE TARGET	VISUAL ID TGT	DETERMINE THREAT CAPABILITIES	EVALUATE RELATIVE TACTICAL POSITION	DETERMINE ATTACK PLAN	EMPLOY APPROPRIATE ENGAGEMENT GEOMETRY MODE	ACHIEVE OFFENSIVE POSITION	MA[illegible] ENERGY	RECOGNIZE LAR	DELIVER WEAPON	EVALUATE RE ATTACK
CONVENTIONAL ACFT OPERATIONS	x	x	x			x	x	x	x	x	x	x
RANGE SUPPORTED ACFT OPERATIONS	x	x	x			x	x	x	x	x	x	x
FULL MISSION SIMULATION	x	x	x			x	x	x	x	x	x	x
OFT	x	x								x	x	
CPT						x						
PTT				x	x	x		x		x	x	
CAI	x			x			x		x	x		
TAPE SLIDE VIDEO	x			x					x			
PROGRAMMED TEXT	x			x								
PLATFORM	x			x								

Figure 3

PRIORITY ANALYSIS

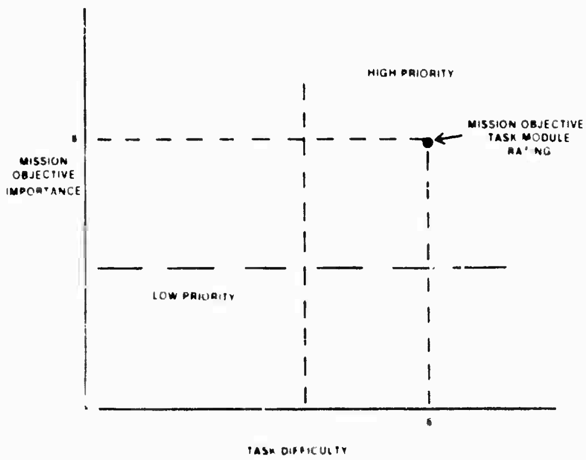

Figure 4

mission effectiveness will most likely be achieved. Conversely, plots which fall in the lower left quadrant represent the lowest priority rating suggesting not more than a modest investment in resources is needed. An example to illustrate the above scheme follows.

From the Instructional Requirements analysis matrix (created in part from the previous mission analysis): (1) it is determined that the mission objective "Determine Attack Plan" is a candidate for advanced simulation training; and (2) from expert interviews it is then decided that this mission objective's relative importance rating is 8. This number is plotted along the Y axis of the graph (Figure 4). (3) The mission phase is then decomposed into its component tasks and a task module Determine Appropriate 1V1 Tactics to Achieve Advantage is identified (Figure 5). (4) Determining the difficulty of this task module is then attempted by examining task loading for this mission phase.

In this hypothetical case multiple tasks need to be performed but under relaxed time conditions (largely because this objective occurs prior to engagement); thus a difficulty rating of 6 is assigned. This number is then plotted along the X-axis (see Figure 4). Where these two numbers intersect represents the relative desirability rating of providing instruction for this mission-related task module utilizing advanced simulation technology. Note in this example it is considered "highly desirable" to utilize advanced simulation systems to train in this area.

The foregoing structured approach is intended to provide a convenient means of specifying and selecting areas where concentrated efforts can achieve the greatest

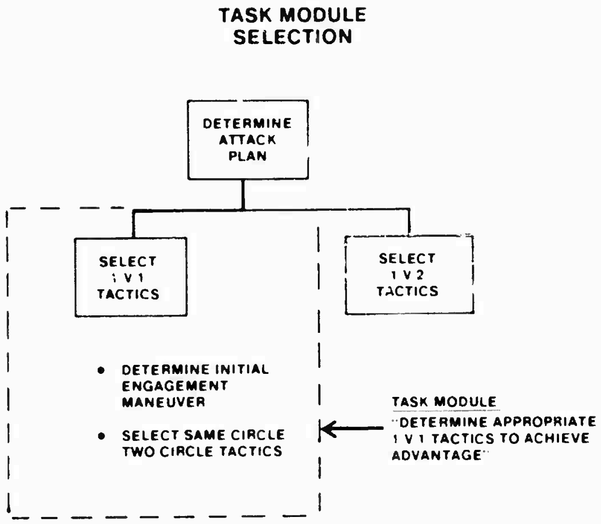

Figure 5

training return-on-investment. In other words, of all of the mission areas that are possible to simulate today, where should we be directing our attention? Clearly, our attention, followed by our resources, should first be directed at the most difficult/most important mission areas. In this way, training systems can be designed that speak directly to critical operational needs. Finally, it is the author's opinion that as our high-technology training systems begin to focus on critical operational needs, their acceptability as well as their utilization rates will show substantial improvements.*

INSTRUCTIONAL DESIGN FEATURES

The most obvious instructional design feature an advanced simulator could possess is a formal curriculum designed to achieve specific training objectives while utilizing the subject device. Unfortunately, this is so obvious that, paradoxically, it has been often overlooked. Numerous instances can be cited where expensive, advanced flight simulators were delivered to the fleet without a supporting syllabi. Fortunately, steps are being taken to rectify this situation and it appears now that most cognizant individuals agree on a need for a supportive instructional program complete with performance feedback for these modern training devices.

*It is recognized that ultimately this priorization analysis must find a logical resting place, such as a direct aid to selecting generic design features of the system under analysis. Additional work is needed in this area and formal support for this and similar efforts is strongly encouraged.

Significant difficulties, however, remain in deciding who should be responsible for curriculum development: prime contractors, squadron personnel (i.e., users) or training specialists. These questions become moot when these devices are viewed from a systems perspective. This view holds that complete instructional systems are needed in this age of complex mission requirements driven by high technology.

For advanced simulators this "training system" could include such operational items as:

- Conventional system hardware and supporting computer software
- Operational training curriculum
- Performance measurement system
- Training management system.

There remains an unfortunate tendency - possibly due to a less than clear view of the "systems approach" - to treat only the first step as sufficiently worthy of the design team's attention. If we can at least tentatively agree that as sophisticated instructional devices, full mission simulators ought to come equipped with a structured training program, (which has the added benefit of requiring contractors to more fully consider operational training problems and requirements) then an important related condition presents itself. How can critical mission objectives be translated into formal curriculum designed to enhance training effectiveness in today's complex mission areas?

To answer this question we must first briefly outline the ISD process and then show how the previous priority scheme can be utilized for the design of enhanced training programs.

Curriculum Development

Development of a training program for advanced flight simulators should clearly follow the ISD (Instructional System Development) process, which provides a systematic and scientific methodology for

o Identifying tasks that (operators) must perform

o Specifying the hierarchy of training objectives

o Developing procedures and schedules for training in the performance of identified tasks.

The ISD model, although providing for improved professionalism in instructional system design, lacks a mechanism specifically designed to spotlight critical mission areas and concomitant priority training requirements. Thus, such critical areas as operator decision-task requirements are largely neglected in present ISD treatments.(3)

Mechanism to Aid in Development of Enhanced Training Products

To aid in the development of enhanced training products, a mission-focused priority scheme for identifying critical mission areas and thus important training requirements is considered essential. The previously outlined "structured approach" is considered a candidate means to accomplish this task.

The process of focusing in on critical mission and training needs commences as before with a formal analysis (Figure 2) of the cognizant mission. The Instructional System Requirement Analysis matrix (Figure 3) then provides a convenient means to identify candidate instructional methods appropriate to the specified mission objectives. From this matrix, we can see for instance, that the mission objective "determine threat capabilities" can be addressed by utilizing any or all of the following training methods:

- Part task trainer
- CAI
- Stand-alone tape/slide/video
- Programmed text
- Platform.

A possible way to determine the most appropriate instructional strategy is to conduct a Priority Analysis to determine relative importance of this mission area. This analysis, explained in detail in the previous section, examines appropriate mission objectives and its component tasks from the standpoint of importance and task difficulty.

When plotted on the Priority Analysis Graph (Figure 4), Mission Objective/Task Modules which fall in the high priority quadrant should drive the development of an instructional system commensurate with this priority. High priority areas may, therefore, require the development of a composite training system embracing the following areas:

o Aircraft operations complete with detailed scenarios

o Simulation training events designed to prepare for specific aircraft operation scenarios.

o Part-task trainer designed to instruct in critical decision-task areas.

o Computer-aided instruction designed to develop requisite background information.

Thus the composite training system concept extending beyond the compartmentalized view of stand-alone training systems, proposes, utilizing the "Structured Approach", to (1) focus on critical mission areas, and (2) integrate various instructional devices (and instrumented ranges) and curriculum into a coherent, goal oriented process whereby enhanced training indeed becomes a reality.

SUMMARY

It appears self-evident that a clear view of mission objectives, tasks, and candidate training methods coupled with a priority scheme is needed in any successful design effort for advanced simulation systems. Indeed, these concepts are finding favor among more and more individuals such as Cream(4) who encourages a task rating system for use in selecting actual simulator design features.

Whatever priority or rating system is adopted, providing design teams with appropriate "mission logic" coupled with a mechanism to focus attention and resources on those areas promising the greatest training return-on-investment appears to be the critical task at hand. No longer can we afford to build high technology systems exclusively from a technical specification document. Technical know-how must be translated into mission capability by making technology respond specifically to critical mission needs. Otherwise we will remain in our current predicament of fielding technical systems that at best only achieve sub-optimum levels of mission performance throughout the system's life-cycle. Thus future distress calls from the operational community will become an increasingly regular and tragic occurrence.

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Graduating from Navy Flight Training in 1965, CDR. Smith spent 14 years on active duty in various assignments flying the F-8 Crusader, accumulating over 2400 hours in type. His major fleet assignments included Officer-in-Charge, Light Photographic Squadron Sixty Three Detachment One (VFP-63 Det 1) deployed in USS Constellation, as well as numerous squadron level department head positions.

When not performing his Naval Reserve duties, Mr. Smith in civilian life is employed as an Airline Pilot and, in addition, is involved in work relating to Mission and Operational Analysis.

Holding a degree in Electrical Engineering, Mr. Smith is also a graduate of the Naval Air Training Command, Tactical Fighter and Tactical Reconnaissance training; and holds an Airline Transport Pilot rating, a Flight Engineer rating and is currently qualified on the Boeing 727.

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IDENTIFYING NECESSARY GOALS AND OBJECTIVES FOR TRAINING SYSTEMS: A NEEDS ASSESSMENT APPROACH

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ABSTRACT

This paper introduces a candidate needs assessment model that has unique potential for identifying military training needs. During the training planning process, planners frequently and inadvertently confuse training strategies (means) with training results (ends). One reason for this confusion is the inherent difficulty in accurately specifying military training needs. The complex nature of military training needs is explored and the potential benefit of the Organizational Elements Model as a planning tool is presented.

Quality military training is a necessary but difficult objective to achieve. The act of bringing together all the necessary ingredients of training systems (e.g., people, training aids, devices and curricula) will not insure effective training. More fundamentally, effective training is the result of careful planning which is based upon accurate need assessments. This paper examines the nature of military training planning from a wide perspective with special attention focused upon the unique characteristics of military training needs. The principle theme is that the planning processes presently in use can be improved by using a relatively new needs assessment technique, thus potentially increasing the probability that effective training systems will be produced.

A NEEDS ASSESSMENT APPROACH: THE ORGANIZATIONAL ELEMENTS MODEL

The Organizational Element Model (OEM) for educational system planning, while currently in the developmental stage, is one method of assessing needs.(1), (2)* The concepts inherent to the OEM apply to all needs inside or outside of any organization. Hence, the OEM will first be discussed in general training and educational terms, followed by specific application to the military training community (i.e., all training commands, their supporting commands, all con tractor organizations that support training efforts, etc.).

*It should be noted that the discussion of the OEM represents a synthesis of Kaufman's writing on the subject. Only primary references are noted in the text.

The main concern of the OEM is the identification of organizational needs. Kaufman(3) defines a need as a gap between "what is" and "what should be" in terms of organizational results. Defining a need as a gap between present and desired results helps to ensure that no solution statements are included within the statement of the needs. In order for effective planning to occur, it is critical that solutions for the need not be introduced too early in the planning process. Considering specific solutions before the need is truly defined often causes the planner to establish biases and to overlook many alternative solutions For example, if a specific solution is incorporated too early (i.e., "what we need is a computer-assisted instruction (CAI) system") the planning will then proceed under the assumption that CAI is indeed the only appropriate solution to the problem. However, had planning proceeded without the assumption about CAI, the requirement may have been met with an instructional delivery system which is less expensive or more appropriate than CAI (e.g., a modularized slide-tape).

By viewing the need as the difference between "what is" and "what should be", solution statements can be clearly separated from needs statements. This separation allows the user of the OEM to explore all aspects of the problem with an unprejudiced outlook.

The OEM, which is composed of five elements, is the tool which relates needs assessment to other aspects of training development, implementation, and evaluation (see figure 1). The first element represents the inputs which the organization receives and uses in accomplishing its objectives. These inputs consist of the existing "raw materials" which are available for use.(4) Examples include: expertise, time, funds, computers, policies, plans, goals, and people.

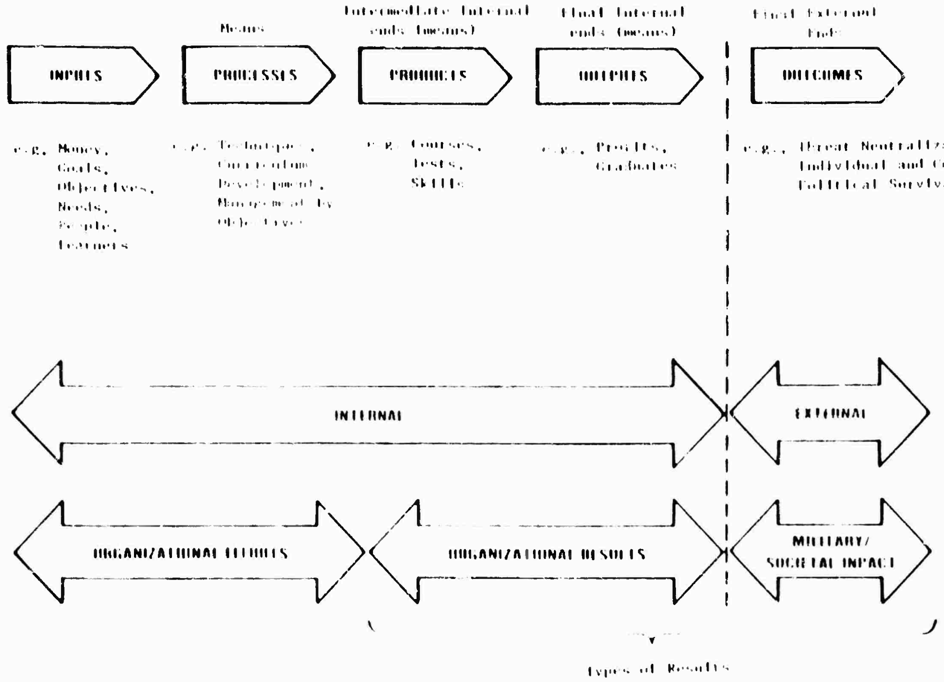


FIGURE 1: THE ORGANIZATIONAL ELEMENTS MODEL

The second element of the OEM consists of organizational processes. These processes consist of the means or solution steps which start the inputs into action. Examples of organizational processes are: management by objective, development of CAI, the systems approach, analyses, research, and the Program Evaluation and Review Technique.

The first two elements represent organization efforts. People within organizations spend most of their time gathering inputs and using them in processes. These first two elements of the OEM (efforts) are used to produce the last three elements which are organizational results.

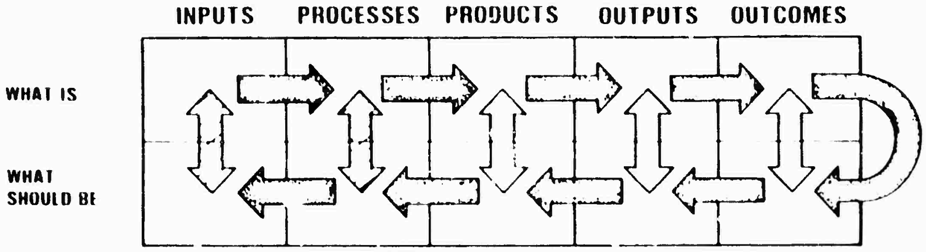
The third element of the OEM consists of organizational products. These are the "things" which the organization produces. These products could be training materials of various kinds (e.g., training devices, curricula, evaluation reports, etc.).

The fourth element consists of the outputs of the organization. These are defined as that which is delivered to the world external to the training community; such as trained personnel (graduates). Products and outputs differ, in that an organization's products are only intermediate results of an organization's efforts. For example, the training community never delivers curricula to the external world. Instead it uses the curricula internally to train personnel. These trained personnel are the outputs which the training community delivers to the external world.

The final and most important OEM element is outcomes of the organization. Societal outcomes are made up of the effects or impacts of the organization's outputs. For example, less crime is reported in society because the graduates of the educational establishment were better trained and thus were better able to obtain gainful employment. In this example, reduced crime is one outcome of better trained graduates. As noted above, the graduates are outputs of the educational system.

Functioning of OEM in a Training Setting

The functioning of the OEM begins with the establishment of a data-base by training system users and developers. Figure 2 shows that the OEM has two dimensions: "what is" and "what should be". This data-base contains information about the training system as it presently exists, and also makes statements about what the training system should be like. The data base is used for the conduct of a discrepancy analysis comparing the "what is" status for each OEM element with the "what should be" status. The two dimensional matrix in figure 2 also suggests the sequence for conducting this analysis. The sequence established for the "what is" status for each element begins with the inputs elements and progresses to the outcomes element. The sequence for establishing the "what should be" status is just the reverse. Experience has shown that the sequence for analyzing "what should be" is necessary for determining the proper linkages between the five elements.(4) Again, when planners consider inputs and processes, before



CHANGE REQUIREMENTS	e.g. Increase funds to procure training devices, increase number of instructors, expand formal school facility and buy extra rounds.	e.g. Incorporate new objectives, and expand courseware, procure new training devices and provide more practice.	e.g. Useful products as measured by trainee learning of requisite skills, knowledge and attitudes.	e.g. 100% of graduates should achieve first round hits in simulated situations.	e.g. 100% of gunners should be effective as measured by ability to hit 95% of targets in combat

FIGURE 2: LINKING PROBLEM SOLVING AND PLANNING TO NEEDS ASSESSMENT INFORMATION

outcomes have been defined, they run th risk of overlooking many possible solution alternatives. The cross-hatched arrows, represent the relationship between "what is" and "what should be" for both the inputs and processes elements. These arrows indicate that the discrepancies are in efforts, not results.

Once the "what is", "what should be" conditions are known, discrepancies between internal and external results can be determined. The OEM makes a distinction between results that are internal to the organization and results that are external to the organization. Examples of internal results from a tank production scenario are: obtaining engines, obtain all sub-assemblies, obtain orders. Examples of external results from the tank production scenario are: tank safety, efficiency, profitability, positive military impact and repeat orders.

The following hypothetical example serves to illustrate this process. The outcome problem can be summed up in the following statement, "NATO Dragon gunners are not proficient marksmen." The hypothetical "what is" status for each OEM element is as follows: (see figure 2)

inputs. Present funding levels for Dragon training; number of instructors; number of practice rounds; ranges; Dragons; and trainees.

processes: Dragon curriculum, practice, qualification (due to limited rounds, the Dragon trainees receive too little practice).

products: Skills, knowledge and attitude necessary to become proficient Dragon gunners. (Due to limited practice the present training does not allow the trainees to achieve the necessary levels of skills, knowledge and attitudes).

outputs: Only 32% of the current graduates achieve first round hits at stationary targets 400 to 600 meters away in simulated situations.

outcomes: Based on simulated practice it is felt that NATO Dragon gunners will be ineffective in actual combat. (This type of outcome statement points up the difficulty of assembling rational "what is" concepts for the military. Since, thankfully, so little live combat takes place we seldom know for sure how effective our outputs are. Analysis of recent combat situations, like the Falklands and Middle East conflicts, are of some help in this area).

The "what should be" conditions are as follows:

outcomes: 100% of Dragon gunners should be effective in the world external to the training community as measured by their ability to hit 95% of their targets in actual combat.

outputs: 100% of graduates should prove that they have learned the requisite skills, knowledge and attitudes as measured by their ability to achieve first round hits at 300 to 600 meters in simulated situations.

products: The training community should develop training products which are useful to Dragon trainees as measured by trainees learning the requisite skills, knowledge, and attitudes.

The "inputs" and "processes" for the "what should be" are not defined yet.

The three "what should be" elements describe the changes which are required to meet the need. Notice that the term "as measured by" is included with each "what should be" statement. It is important that the criterion benchmarks for success be established early in the planning process. It is also important to note that there are no specific solutions presented. Solution alternatives are developed later when inputs and processes are considered. The inputs and processes are concerned not with what must be done, but rather with how it should be done. In this particular example, the processes used may include the formal school expanding its objectives and supporting courseware as well as incorporating a training device. To support the process elements, the inputs should reflect an increase in funds, number of instructors, and number of practice rounds.

In summary, this process of describing the current "what is" and the ideal "what should be" for each of the five elements is potentially applicable to most military training situations. How the OEM can assist the current planning process is addressed below.

CONFUSION OF ORGANIZATIONAL MEANS AND ENDS

Too often the ultimate goal of the military training effort is lost in, or confused with, the multitudes of processes and products which are involved in the delivery of a training system. These products and processes may satisfy the training community's internal needs (e.g., training courses, training devices, graduates, continued funding), but they do not necessarily satisfy the proper external need - that of military preparedness (i.e., combat effectiveness).

A commonly observed example of a means-ends confusion is a "state of-the-art" training device that the user finds marginally useful (user in this paper refers to the operational community). The term, "state-of-the-art", in this situation, implies that this device contains the latest in technological sophistication. Yet this sophistication alone does not ensure user acceptance or eventual combat effectiveness. User comments about the device may include complaints about the lack of fidelity in the device's controls, confusing feedback displays, and worst of all, the observation that the device does not assist in producing trained personnel. The problem is that the device's sophistication applies only to its technological components (the means for delivering training) and not to how they function to produce combat effectiveness.

Although the means vs. ends confusion in the planning process has many causes, this paper will address only two. The first reason is the misplaced emphasis upon internal results while eschewing user concerns (external results). The second reason for the means vs. ends confusion is the inherent difficulties in defining military training needs. The nature of these causes and how the OEM can assist planners in reducing the means vs. ends confusion are developed below.

Training organizations often and inadvertently emphasize internal results as opposed to external results. That is, training organizations often derive their own internal objectives (e.g., receiving money, developing training devices, graduating students, etc.) and pursue them. Such internal objectives are important; they allow organizations the opportunity to determine progress towards an ultimate end. However, problems occur when an organization becomes so concerned with these internal objectives that it fails to properly identify and meet external ends. The training organization becomes so focused on the "how to do its" that it fails to meet the larger needs of the society it serves. In the case of military training organizations the external referent is the operational force. Whenever a training organization becomes so set on achieving its own internal objectives, to the exclusion of the external society it serves, detrimental consequences can and do occur. Because the OEM clearly defines the relationship between internal results and external results, its use in the planning process may assist in averting this cause of confusing means and ends.

The second reason for confusing means and ends in the planning process is the difficulty encountered in accurately defining military training needs. Specifically, there are three characteristics inherent to military training needs that must be systematically addressed.

The first characteristic of military training needs is the way in which they are specified. Training needs usually evolve after the relations between the threat, doctrine and force structures are defined. At this point the training need is usually expressed as a gap between the current force status (what is) and a future optimal status (what should be). This gap (or need) is most often expressed in general terms of military capabilities, which are related to combat effectiveness, and military political impact. The OEM's distinction between training outputs and outcomes may be useful to planners in coping with this characteristic. For example, outcomes should be stated in terms of combat effectiveness.

The second characteristic of military training needs is related to where the training requirements are specified in the Department of Defense. Military training requirements originate from two basic sources mostly outside the training community: the parent service (i.e., Air Force, Army, Marines, Navy) and the Commanders in Chief of the unified commands[5]. The parent service is charged statutorially to provide, among other items, "Unit mission proficiency standards for the conduct and evaluation of training. These are developed from current doctrine and force structure."(5) The unified chain of command provides some training requirements when it states mission specifications and performs contingency planning. Although the training community may assist in defining training needs, it is the user community which must make the final decision. Hence, it is imperative for the planner to clearly define the nature of the need to be addressed in the tasking. The OEM can assist the planner in determining whether the tasking is requesting an internal result (products, or outputs) or an external result (outcome).

The third characteristic of military training needs is that they experience what may be described as a translation process as they are passed from higher to lower commands. An oversimplified example is depicted in figure 3. As noted earlier, a training need is defined at the highest echelons of command. Training needs are then translated into concrete program efforts by a variety of commands subordinate to the top levels. These programs are often composed of several projects. This translation process is not well understood and the training needs may be altered in the extreme from one command to the next. They are unfortunately omitted entirely in some translations.

An additional aspect of the translation process which adds to the confusion is that personnel with varied backgrounds and technical disciplines become involved. At the top echelons of command, the training need is discussed in terms of abstract military operations and the principles of war. As the statement of the training need is passed to lower echelons it becomes more concrete. The five elements of the Organizational Elements Model are considered and the management of the training system is defined. At the project level the need is translated into the language of human learning and performance, man-machine interfaces, etc. At the top levels the (abstract level), training needs are described as "what must be done". As the needs are passed down to the middle and lower commands (concrete levels) they are expressed as "how to get it done". Should this orderly process be altered (i.e., the "how to get it done" is addressed before the "what must be done") confusion of means and ends is likely to occur.

The OEM's five elements appear to have some rough correspondence to the translation process. For example, lower echelon efforts may be classified as inputs and process efforts while higher echelon concerns fall within products, outputs, outcomes categories. However, the "translation process" per se is little understood and must be investigated before it can be adequately addressed by planners.

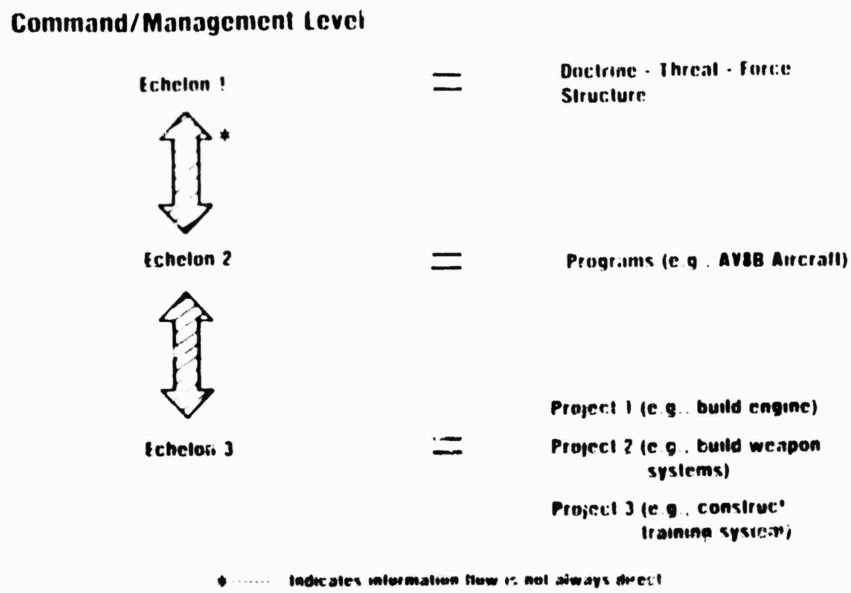


Figure 3. The Translation Process: Translating Operational Needs into Training Needs

SUMMARY AND CONCLUSIONS

Confusing training means and ends can greatly hamper the attainment of effective training. The confusion of means and ends can be eliminated by careful planning which is driven by accurate identification of user needs. Planners must be aware of how needs are stated and where they originate. Additionally, the process of translating needs from upper to lower levels of command must be continually addressed.

The training community can improve its performance by making the distinction between inputs, processes, products, outputs and outcomes in its planning efforts. With the ever increasing requirement for efficient and effective training in the military, it is vitally important that the military training community understand user needs. Although the Organizational Elements Model presented here is still in development, it is one approach to needs assessment that has potential applicability to military training.

The training community is often not as effective as it might be because it confuses means and ends by concentrating more on processes and products and not on outcomes. This narrow perspective, which emphasizes the internal needs of the training community, and often excludes the external needs of the operational forces, results in low training validity. Consequently, disillusionment with the training community is a result. Careful attention to user needs will help to produce training which improves the nation's ability to prevent armed hostilities through strength if possible, and to win a swift and complete victory if necessary.

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THE COST-EFFECTIVENESS OF MILITARY TRAINING

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ABSTRACT

The use of flight simulators, computer-based instruction and maintenance training simulators for training is evaluated on the basis of their effectiveness and cost. Flight simulators are cost-effective, compared to the use of aircraft, for training; so are maintenance training simulators compared to actual equipment trainers. Computer-based instruction is as effective as conventional instruction; comparable ~~cost~~ data are not yet available, so one cannot say whether it is also cost-effective. These three methods of training are not more effective than the methods to which they were compared, except for small improvements in a few cases. It is possible they could be made more effective if cost savings were not a major goal, but this remains to be determined. The goal of analyses of training should be an ability to perform trade-offs of the effectiveness and costs of new methods of training, but no such trade-offs have yet been made.

PURPOSE

The purpose of this paper is to evaluate both the cost and effectiveness of military training in three areas where relevant data are available: flight simulators, computer-based instruction, and maintenance training simulators.

THE MAGNITUDE OF MILITARY TRAINING

Military training makes a large and continuing demand on resources allocated to the military services. For example, the time spent by students in individual training at designated schools plus that of the instructors needed at those schools accounts for about one-fourth of all the man-years (both military and civilian) available to the Department of Defense (Figure 1). About 20 percent of all military personnel are in schools at all times, either as students or instructors. Most (about 76 percent) of this effort simply provides initial training to new personnel entering military service for the first time.

Individual training at military schools will cost $12.8 billion in Fiscal Year 1983. The types of training vary widely by number of students and cost per student, as shown in Figure 2. This information can help tell us where improvement in training could have large impact. For example, specialized skill training involves the largest number of students and costs more than any other type of individual training. Undergraduate flight training, for pilots and other aircrew, has the smallest number of students, but it costs much more per student than any other type of individual training.

It may be noted, in passing, that a student needs additional training after he leaves school. This is known, variously, as on-the-job training, advanced flight training, crew training, and field exercises. None of the costs of additional training needed after leaving a school is included in the data shown in Figure 2.

Finally, it may help to know that the cost of individual training at school is nontrivial when compared to other, readily available, costs in the annual military budget. As shown shown in Figure 3, individual training at school costs about half (or more) of what is spent for intelligence and communications, the strategic forces, or for all research, development, test, and evaluation; and roughly 15 percent of how much is spent for procurement or operation and maintenance. Military training is a major component of the military budget. Operational readiness depends on effective training. It is possible to realize the high levels of performance built into our advanced weapon and support systems only if these systems are maintained and operated according to their design specifications, and this also depends on effective training. Thus, it is almost mandatory to have effective training; improvements in our current methods of training are likely to have useful and significant payoffs.

There is, generally, more than one way of training most skills, e.g., group lectures, individual coaching, use of simulators, and so on. The first question which must be answered--whether it concerns new or current technology--is, "Is it any good? Does it train as well as, or perhaps, better than some other way we could use?" This is the issue of effectiveness of training. But the effectiveness of training cannot be addressed meaningfully without also considering its

	MAN-YEARS (000)	
	MILITARY	CIVILIAN
STUDENTS	255	—
INSTRUCTORS	133	59
TOTAL	388	59
DoD END-STRENGTH	2148	1035
PERCENT IN TRAINING	18%	6%

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FIGURE 1. The Amount of Time Spent by Students and Instructors in Individual Training at Military Schools, FY 1983 (Source: Military Manpower Training Report for FY 1983; Weinberger 1982).

TYPE OF INITIAL TRAINING	NUMBER OF STUDENTS (INPUT, 000)	COST	APPROXIMATE COST/STUDENT
RECRUIT	363	$ 871 M	$ 2 K
ONE-STATION UNIT TRAINING (ARMY)	119	332	3
OFFICER ACQUISITION	20	376	19
SPECIALIZED SKILL	1,347	2,883	2
UNDERGRADUATE FLIGHT	18	1,825	100
PROFESSIONAL DEVELOPMENT EDUCATION	35	427	12
MEDICAL	—	431	
SUPPORT, MGMT, TRAVEL, PAY	—	5,626	
TOTAL		$12,771	

6-24-82-6

FIGURE 2. Number of Students and Costs of Various Types of Individual Training at Military Schools, FY 1983 (Source: Military Manpower Training Report for FY 1983).

ITEM	COST (Billions)	INDIVIDUAL SCHOOL TRAINING, AS PERCENT OF OTHER COSTS
INDIVIDUAL SCHOOL TRAINING	$12.8 B	
INTELLIGENCE AND COMMUNICATIONS	18.0	71%
STRATEGIC FORCES	23.1	55
RDT&E	24.3	53
OPERATION AND MAINTENANCE	70.4	18
PROCUREMENT	89.6	14

FIGURE 3. A Comparison of the Budgets for Individual School Training and Other Major Military Expenditures, FY 1983 (Source: Weinberger 1982).

cost. Almost any method of training could be made effective if enough money for equipment and instructors and long training time for students students were made available. Therefore, if two methods of training are equally effective, we should select the one that costs less. If two methods of training cost about the same, we should select the one that is more effective. If a new method of training is more effective and costs less, the choice is easy and obvious, but such opportunities are rare.

We will consider next comparisons of the effectiveness and cost of three types of training: flight simulators and aircraft, computer-based instruction and conventional instruction, and maintenance training simulators and actual equipment trainers. This will be followed by a discussion of what the results mean for future evaluations of training.

FLIGHT SIMULATORS(1)

The extent to which flight simulators should be used in flight training is a major concern to all military services. The key questions are obvious:

- do flight simulators really train pilots
- do the skills learned in flight simulators transfer readily to aircraft
- are flight simulators worth what they cost

The last question cannot be ignored since the cost of some modern flight simulators, when equipped with advanced visual systems and motion bases, approaches the cost of aircraft.

The procurement of new simulators, including major improvements to those acquired previously, has averaged about $275 million per year for the last eight years (Figure 4). It costs about $3.6 billion per year for fuel and supplies needed to operate military aircraft. About 7,600 new pilots will be qualified in fiscal year 1983 at a cost of about $1.8 billion.

How much does it cost per hour to operate simulators and aircraft? Figure 5 shows comparable operating cost data for 42 pairs of flight simulators and aircraft for fiscal years 1980 and 1981. Variable Operating Costs, as shown here, are for fuel, oil, and spare parts consumed as a function of use; the costs of pay and amortization are not included in these amounts. The median ratio of simulator/aircraft operating costs is 0.08; it was 0.12 in fiscal years 1975 and 1976.

The fact that flight simulators cost less to operate than aircraft is a useful but not conclusive finding unless we also know how well they may be used to train pilots. The effectiveness of a flight simulator may be evaluated by determining how much time, if any, it saves in training pilots to perform specific tasks in an airplane, compared to the amount of time required for such training only in the airplane. The same level of performance in aircraft is required in both cases. It has long been known that pilots can perform in the air, more or less well, tasks learned in flight simulators. The real question is how good

(1) This information is based on Orlansky and String, 1977.

PROCUREMENT OF SIMULATORS	$0.275 B/YR	FY 75-82
ALL FLYING COSTS	$3.6 B/YR	FY 1981
UNDERGRADUATE PILOT TRAINING		FY 1983
INPUT	9337	
OUTPUT	7603	
LOAD	5581 MAN-YEARS	
COST	$1.8 B	

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FIGURE 4. Major Costs Associated with All Flight Training.

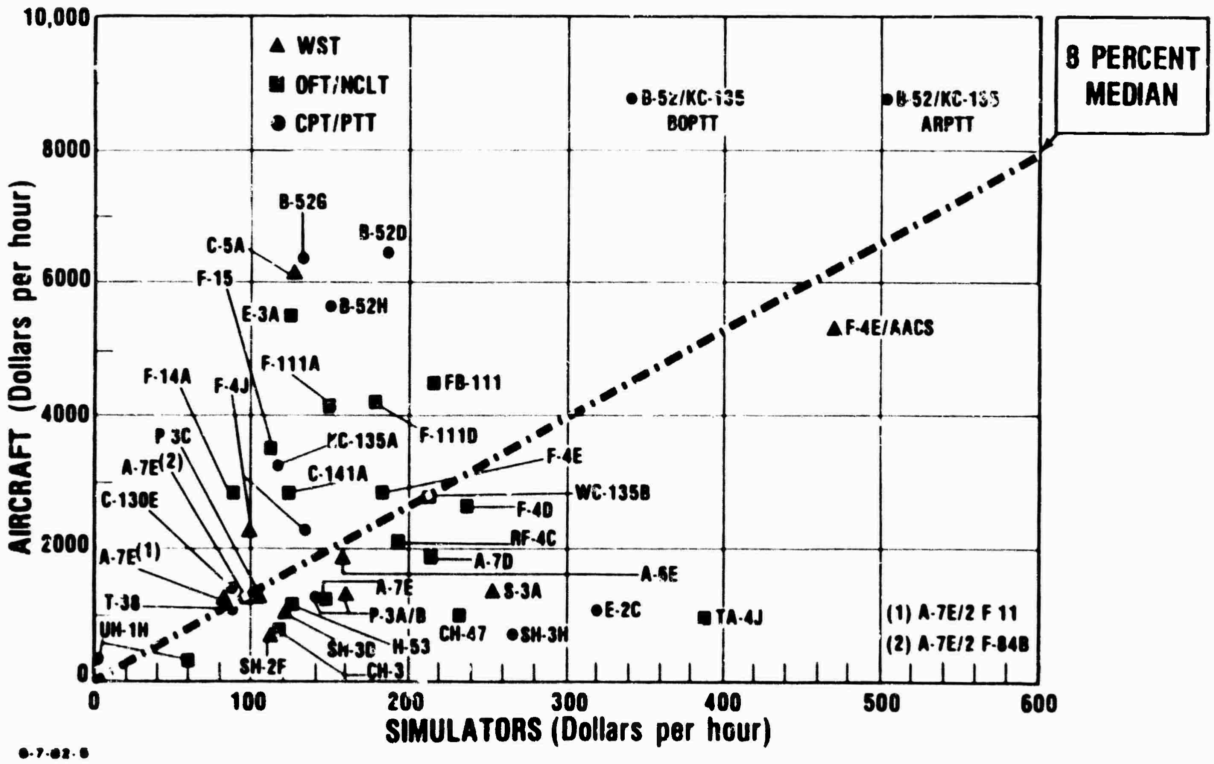

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FIGURE 5. Variable Operating Costs Per Hour for 42 Flight Simulators and Aircraft, FY 1980 and FY 1981.

is this training. An index, called the Transfer Effectiveness Ratio (TER), shows the amount of flight time saved as a function of the amount of time spent in the simulator (Figure 6).

Transfer effectiveness ratios from 34 different studies of flight training (e.g., basic contact flight, instrument flight, ASW maneuvers, multi-engine transition) are shown in Figure 7. The TERs range in value from -0.4 to 1.9, with a median value of 0.48. Using the median value, the data show that pilots trained in simulators needed less time in aircraft to perform acceptably than pilots trained only in aircraft; the amount of flight time saved was about one-half of the time spent in the simulator. There is a wide range in these TERs; clearly, these flight simulators were not equally effective in saving flight time in all cases, and it seems important to identify the factors that make for efficient and inefficient uses of simulators.

Since flight simulators save about 50 percent of the time needed by pilots to train in aircraft and cost only 8 percent as much to use (median values in both cases), it is clear that flight simulators are cost-effective, compared to the use of aircraft alone for training. The amount of such savings, after providing for the cost of these using simulators, is shown for three cases in Figure 8; the savings were large enough to amortize the procurement cost of flight simulators within two years or less.

COMPUTER-BASED INSTRUCTION(2)

The question addressed here is whether instruction that is supported by the use of computers is cost-effective compared to conventional, classroom instruction. Conventional instruction is based largely on lecture, discussion, and some amount of individual coaching. Its salient features are group-pacing, and some amount of individual attention. Conventional instruction was compared to two new methods of instruction, both using computers, that have been developed since about 1960. The first method, Computer-Assisted Instruction (CAI), involves placing all the instructional material in the computer. It provides lessons to the student by means of a cathode ray tube; the student may respond by such means as a keyboard or by touching the screen. The computer guides the student, corrects him as needed, and provides new or explanatory material to suit his method of learning; the computer maintains student progress records and can provide a variety of administrative information needed to operate a course and/or school. In the second method, Computer-Managed Instruction (CMI), the student receives his instruction away from the computer, i.e., in a learning carrel or at a laboratory bench. However, he takes a test on some amount of course material, typically after about one hour's worth of instruction. The computer scores the test, interprets the results for the student, and directs him to his next lesson or to repeat the last one. The computer performs a similar evaluation and guidance function in both cases, except that it is based on individual responses in CAI and comes only after tests in CMI. The salient features of CAI and CMI are that each student proceeds at his own rate of learning ("self-paced" instruction) and receives frequent feedback on his progress. This may be contrasted with group-paced instruction where tests are spaced further in time (daily, weekly or monthly) and where all students must proceed at the same pace despite known differences in rate and/or style of learning.

Computer-assisted and computer-managed instruction are significant alternatives to conventional instruction primarily in specialized skill training. About 1.4 million students are trained in various special skills at a cost of about $2.9 billion each year (Figure 9). Most (76 percent) of these students are "new accessions", i.e., personnel recently admitted to the military services who are being trained for their first military assignment. There is a continuous need to train replacements for those who now leave the military services after relatively short careers.

CAI and CMI may have many advantages, but the fundamental question must be how effective they are, compared to conventional instruction, in instructing students. This issue has been addressed in 48 studies, conducted from 1968 to 1979, that are summarized in Figure 10. Using grades in end-of-course tests as a measure, these studies compared achievement of students in the same courses when taught by conventional instruction or by CAI or CMI. Six different CAI systems and two different CMI systems were compared in a wide variety of technical training courses. Student achievement with CAI or CMI is shown in the figure either as "inferior", "same", or "superior" to achievement with conventional instruction for the same course; the result of each study is represented by a dot placed in the appropriate column. The figure shows clearly that student achievement at school with CAI or CMI is about the same as, or in some cases superior to, that with conventional instruction. The amount of superior achievement (i.e., higher scores) is not large.

In conventional instruction, the rate at which new information is presented is based on about how much the average student can absorb. The entire class proceeds at the same rate (called "group-pacing" or "lock-step" instruction); this pace necessarily holds back student who can learn at a faster rat . With CAI and CMI, each student proceeds at his own rate. Thus, we should expect that students instructed by CAI or CMI should complete their courses in less time, on the average, than those taught by

(2)Based on Orlansky and String, 1979.

$$TER = \frac{A - A_S}{S}$$

A = AIRCRAFT TIME, WITHOUT SIMULATOR

A_S = AIRCRAFT TIME, AFTER SIMULATOR

S = SIMULATOR TIME

FIGURE 6. Transfer Effectiveness Ratio (TER) (Source: Roscoe 1971, 1972).

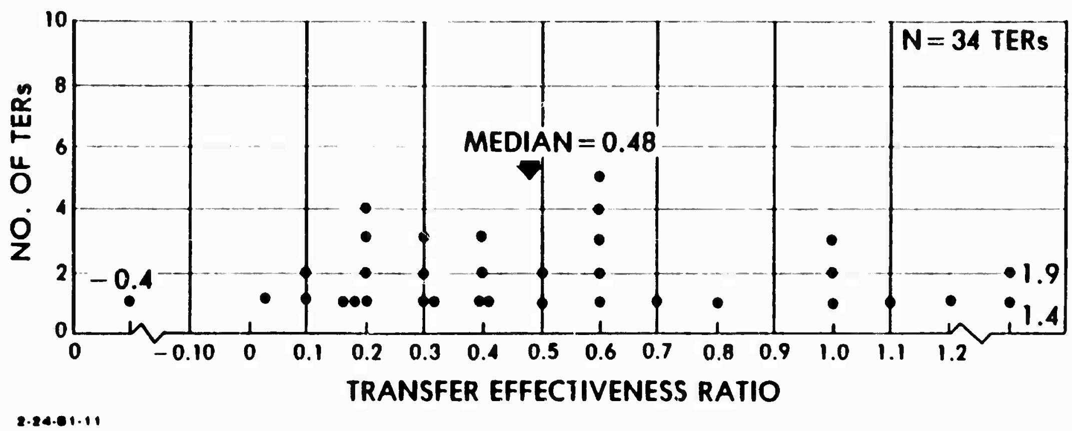

FIGURE 7. Transfer Effectiveness Ratios for Various Types of Flight Training, Based on 22 Studies Performed 1967-1977.

SIMULATOR	PROCUREMENT COST	SAVINGS PER YEAR	PROCUREMENT COST/ SAVINGS PER YEAR
COAST GUARD, HH-52A HH-3F	$ 3.1 M	$ 1.5 M	2.1 YEARS
NAVY, P-3C	4.2 M	2.5 M	1.7 YEARS
AIRLINE	17.5 M	25.3 M	8.3 MONTHS

FIGURE 8. Amortization of Flight Simulators.

SPECIALIZED SKILL TRAINING FY 1983

1,350,000 STUDENTS

76 PERCENT NEW ACCESSIONS

$2.883 BILLIONS

[illegible]

FIGURE 9. The Magnitude of Specialized Skill Training, FY 1983.

FIGURE 10. Student Achievement at School: CAI and CMI Compared to Conventional Instruction.

METHOD OF INSTRUCTION	SYSTEM	SERVICE	LOCATION	STUDENT ACHIEVEMENT AT SCHOOL (compared to conventional instruction)			TYPE OF TRAINING
				INFERIOR	SAME	SUPERIOR	
CAI	IBM 1500	A	SIGNAL C&S		• • • •	• •	ELECTRONICS
		N	SAN DIEGO			• • • • •	ELECTRICITY
	PLATO IV	A	ABERDEEN		• • •		MACHINIST
		N	SAN DIEGO		• •	• • • •	ELECTRONICS
		N	SAN DIEGO		• •		RECIPE CONVERSION
		N	NORTH ISLAND			•	A/C PANEL OPERATOR
		AF	SHEPPARD		• •	• •	MEDICAL ASSISTANT
		AF	CHANUTE		• • • •		VEHICLE REPAIR
	LTS-3	AF	KEESLER		• •	•	ELECTRONICS
		AF	KEESLER		•		WEATHER
	TICCIT	N	NORTH ISLAND		•		TACTICAL CO-ORD. (S-3A)
	1600M	N	DAM NECK	•	•		FIRE CONTROL TECHNICIAN
	PLATO IV	N	DAM NECK		• •		FIRE CONTROL TECHNICIAN
				TOTAL 1	24	15	
CMI	NAVY CMI	N	MEMPHIS		• •		AVIATION FAMILIARIZATION
		N	MEMPHIS		• •		AV. MECH. FUNDAMENTALS
	AIS	AF	LOWRY		•		INVENTORY MGMT.
		AF	LOWRY		•		MATERIEL FACILITIES
		AF	LOWRY		•		PREC. MEASURING EQPT.
		AF	LOWRY		•		WEAPONS MECHANIC
				TOTAL 0	8	0	

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conventional instruction. Data on student time savings, drawn from the studies on student achievement reported above, are shown in Figure 11. The average amount of student time saved by CAI or CMI, compared to conventional instruction, shows a very wide range--from -30 percent to as much as 85 percent (i.e., in a few cases, CAI or CMI took more time). The median value is a time saving of about 30 percent.

There are few data that compare the costs of CAI or CMI and conventional instruction for the same course, and these comparisons tend to be incomplete. Data on student time savings appear to be reliable; however, many other costs must also be considered, e.g., for program development (hardware, course materials, programming), the delivery of instruction (instructors, support, supplies, repairs), and student pay and allowances. No such comparison was made in any of the studies reported above that contained data on student achievement and time saved.

It is often suggested that computer-based instruction is cost-effective because the cost of computers has declined dramatically in the last few years. This true statement can be misleading because it overlooks the fact that the costs of developing software and course materials (both labor-intensive) have been increasing over the same time period. Some studies on the cost-effectiveness of the PLATO IV system (at Aberdeen Proving Ground, North Island, and Chanute Air Force Base) and the Air Force Advanced Instructional System (at Lowry Air Force Base) were conducted during the period of 1975 to 1978. The general findings were that, compared to conventional instruction, these systems were, at that time, either marginally cost-effective or not cost-effective. None of these studies can be represented as conclusive or used as a basis for judgment at the present time because of the large improvements in computer technology that have taken place since they were completed.

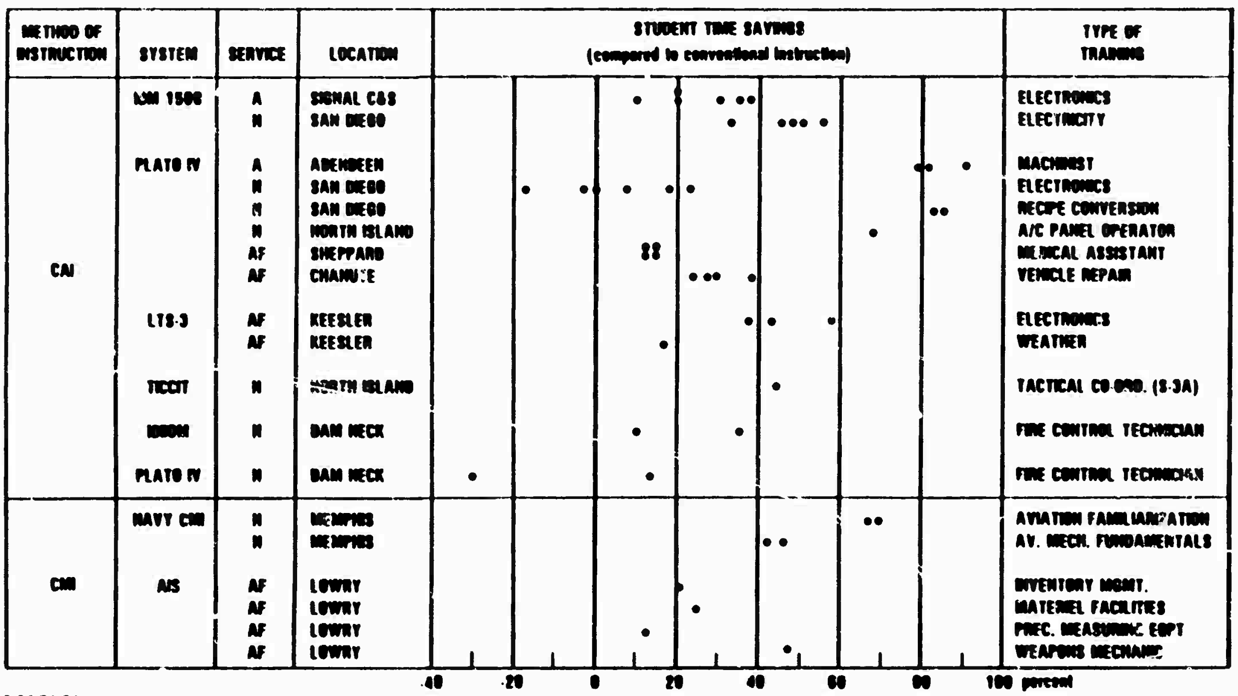
Thus, it can be said that computer-based instruction is as effective as conventional instruction on the basis of student achievement at school, and that it saves student time needed to complete various courses. However, comparisons of the total costs of these methods methods of instruction, using current data and technology, remain to be accomplished.

MAINTENANCE TRAINING SIMULATORS[3]

Operational equipment is used often at schools to train technicians how to perform routine maintenance, diagnose malfunctions, and replace faulty parts. It seems reasonable to do this because trainees will have to maintain the same equipment later in the field. In addition, actual equipment needed for training can be acquired readily by buying an additional unit off the production line. Unfortunately, the use of actual equipment is not

[3]Based on Orlansky and String, 1981.

FIGURE 11. Amount of Student Time Saved by CAI and CMI, Compared to Conventional Instruction



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necessarily the most effective way to train new technicians. The instructor must be able to insert "faulty" parts in order to demonstrate fault finding procedures. Apart from the fact that it takes some time to prepare each lesson on faults, there will be, at best, a limited repertoire of faults that can be illustrated. Wear and tear on "failed" parts makes them easy to detect with little regard to the particular malfunction that is being demonstrated. Major faults or casualties are not introduced in large systems where the investment cost is high for fear of damaging the trainer. For the same reason, only the instructor makes calibrational or adjustment changes. Cascading casualties are difficult if not impossible to induce into real equipment. Further, it is dangerous to use some operational equipment in a school because of high voltages or pressures; operational equipment may break down at school because of abuse by students, not be ready when needed for training, and may entail high maintenance costs.

Most of these limitations may be overcome by using maintenance training simulators, rather than actual equipment, to train technicians. Such simulators always incorporate some type of computer-based control. Thus, it is easy to provide a large number of malfunctions (e.g., combinations of instrument readings and non-responsive controls) that an instructor can easily and quickly select. Simulators can be made both safe for use and resistant to abuse by students. Above all, being computer-based, such simulators can record student performance and provide knowledge of results that otherwise would require fulltime observation of every student by a qualified instructor. The use of maintenance simulators is increasing gradually, primarily in aircraft applications (Figure 12).

The effectiveness of maintenance simulators and of actual equipment trainers has been been compared in about 15 studies conducted from 1967 to 1980 (Figure 13); five different types of simulators were evaluated. The findings are as follows:

1. Simulators were as effective as actual equipment trainers.
2. Simulators saved some student time.
3. Students favored simulators more than instructors did.

Relatively complete data on the acquisition costs of maintenance simulators and of comparable actual equipment trainers are available in 11 cases. Since these maintenance simulators are prototype equipments, they include costs both for development and for fabricating a single unit. Therefore, two estimates were developed for the acquisition cost of a maintenance simulator: a high estimate that includes the cost of research and development plus the cost of fabricating one production unit; a low estimate that includes only the cost of fabricating one production unit. The cost of an actual equipment trainer is the recurring production cost plus the cost of modifying that unit to make it useful at school.

The acquisition cost of maintenance simulators is between 0.20 to 0.60 as much as that for comparable actual equipment trainers, depending on the method used to estimate the cost of the simulator (Figure 14). The lower ratio is probably the more meaningful comparison because it excludes the costs of research and development both for simulators and actual actual equipment trainers. However, a comparison limited only to acquisition costs overlooks the long term costs of using simulators and actual equipment trainers.

Only one complete cost-effectiveness evaluation of a maintenance simulator and its comparable actual equipment trainer has been found. This was a 15 year life-cycle cost comparison of the Air Force 6883 Avionics Test Bench 3-Dimensional Simulator for the F-111 aircraft and the actual equipment trainer (Cicchinelli, Harmon, Keller and Kottenstette, 1980). The study finds that both were equally effective, as measured by student performance at school and by supervisors' ratings of performance of course graduates later on the job. Savings due to use of the simulators are due primarily to lower operating costs over the period of interest. With these savings, the acquisition cost of the simulator can be amortized within four years (Figure 15).

DISCUSSION

The findings of these studies on the cost-effectiveness of selected types of military training are summarized in Figure 16; the values are rounded off. The overall interpretation must be that innovations to training in these areas are as effective as the methods and/or equipments to which they were compared. Where cost data are available, the innovations cost less to procure and use than the systems they can replace. Thus, research and development on training has led to innovations that are cost-effective. This overall conclusion must be qualified because some of the data are incomplete, as discussed next. Credible data that compare the complete costs of computer-based instruction and conventional instruction have not yet been developed. This applies also to the operating and life cycle costs of maintenance simulators and of actual equipment trainers. There is a need not only for more complete cost data but for data that can be used to identify the high cost elements (i.e., cost-drivers) in such training systems; such data are needed also to develop cost-estimating relationships for estimating the probable costs of new training systems.

It is important to note that the effectiveness of computer-based instruction and of maintenance simulation has been demonstrated only on the basis of student achievement at school. Such data do not tell us how well these students perform on the job, and job perform-

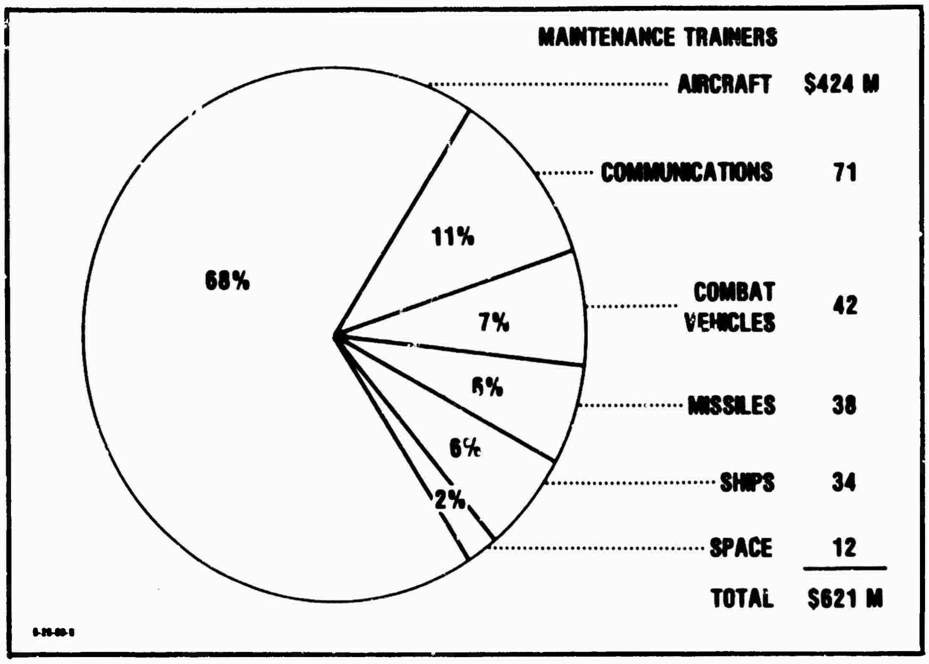

FIGURE 12. Estimated Procurement of Maintenance Trainers (Simulators and Actual Equipment) by the Department of Defense, According to Type of Application, 1977-1985 (Estimated November 1979).

FIGURE 13. Studies on the Effectiveness of Maintenance Simulators, 1967-1980.

SIMULATOR	COURSE	COURSE LENGTH (STANDARD)	COMPARISONS: SIMULATOR TO ACTUAL EQUIPMENT							REFERENCE
			NO. OF SUBJECTS(3)	EFFECTIVENESS(1)				ATTITUDE TO SIMULATORS(2)		
				POORER	SAME	BETTER	TIME SAVINGS	STUDENTS	INSTR.	
Generalized Sonar Maintenance Trainer	Sonar maintenance (special course)	4 days(3)	9		•		22%(4)	Students favorable		Parker and DePaul, 1967
	Intermediate General Electronics	4 weeks	20		•					DePaul and Parker, 1969
EC II	APQ-126 Radar		17					+		Spangenberg, 1974
	Mohawk Propeller System	3 hrs	33			•				Darst, 1974
	Hydraulic and Flight Control	32 hrs	13		•	•		+	−	Wright and Campbell, 1975
	Engine, Power Plants and Fuel	24 hrs	13	•	•			+	−	Wright and Campbell, 1975
	Environmental/Utility System	32 hrs	9		••			+	−	Wright and Campbell, 1975
	APQ-126 Radar	60 hrs	15		••			0/+	0/+	McGuirk, Pieper, and Miller, 1975
										Platt, 1976
								+	+	Biersner, 1975
	Pilot Familiarization, T-2C	10 hrs	8						+	Biersner, 1976
	Flight Officer Familiarization, TA-4C	11 hrs	30						+	Biersner, 1976
Automated Electronics Maintenance Trainer	FM Tuner									Modrick, Kanarick, Daniel, and Gardner, 1975
	Power Control for ALM-84 Test Equip									Modrick, Kanarick, Daniel, and Gardner, 1975
	ALM-106(1) Test Set									Modrick, Kanarick, Daniel, and Gardner, 1975
	Visual Target-Acquisition System									Modrick, Kanarick, Daniel, and Gardner, 1975
Generalized Maintenance Training System	SRC-20 UHF Voice Command System		20				ABOUT 50%	+		Rigney, Towne, King, and Moran, 1978
	SPA-66 Radar Repeater	16 hrs	10					+		Rigney, Towne, Moran, et al., 1978
Fault Identification Simulator	Hagan Automatic Boiler	5 wks	16		•		ABOUT 50%			Swezey (in [illegible] 1979)
6883 Converter/Flight Control Systems Test Station	F-111 Avionics Maintenance	6 days(5)	60		•			+	0/+	Cicchinelli, Harmon, Keller and Kottenstette, 1980

(1) Some studies provide more than one comparison.
(2) + favorable, 0 neutral, − negative, 0/+ neutral to mildly favorable
(3) Simulator only
(4) Average of five maintenance tasks in [illegible]
(5) [illegible] with 6883 takes 2 days in a [illegible]-week course; 6 days in this special [illegible]

11-10-80-11

	SIMULATOR/AET
HIGH ESTIMATE RDT&E + 1 UNIT	0.60
LOW ESTIMATE RECURRING	0.20

FIGURE 14. High and Low Estimates for the Acquisition Costs of Maintenance Simulators/Actual Equipment Trainers.

AMORTIZATION	
ACQUISITION COST	\$595 K
SAVINGS PER YEAR	\$160 K
$\text{AMORTIZATION} = \frac{\$595}{\$160} = 3.7 \text{ YEARS}$	

FIGURE 15. Amortization of the 6883 Test Stand, Three-Dimensional Maintenance Simulator (Source: Cicchinelli, Harmon, Keller and Kottenstette, 1980).

EFFECTIVENESS	FACTOR	SAVINGS OR COST FLIGHT SIMULATORS	 COMPUTER-BASED INSTRUCTION	 MAINTENANCE SIMULATORS
ABOUT THE SAME	STUDENT TIME	50% OF SIMULATOR TIME	30%	20-50%
	ACQUISITION COST	30-65%	?	20-60%
	OPERATING COST	10%	?	50%
	LIFE-CYCLE COST	65%	?	40%
	AMORTIZATION	2 YEARS	?	4 YEARS

FIGURE 16. Summary of Findings on the Effectiveness and Cost of Flight Simulators, Computer-Based Instruction and Maintenance Simulators.

ance is the more relevant measure of training effectiveness. This observation applies equally to conventional instruction. One exception to these comments is that supervisors' ratings showed about the same job performance for students trained either with the 6883 simulator or actual equipment; however, supervisors' ratings are not objective performance measures. On-the-job performance measures are an inherent aspect of evaluating flight simulators because all students who were trained in simulators were observed later in aircraft in flight, as were obviously those trained only in aircraft. However, measures of student performance in aircraft are based on instructors' ratings on well-developed rating scales rather than on objective measures recorded by instruments. It may well be that, regardless of method of training, performance at school does not predict later performance on the job. Whether there is a high or low degree of relationship between measures taken at school and later on the job is an important question that still remains to be answered for almost all types of training.

A basic premise of innovations to training such as flight simulators, computer-based instruction and maintenance simulators, is that they will improve the quality of instruction and, thus, the effectiveness of training. The basic findings, as reported above, are that these innovations to training are about as effective as the methods they can replace and save appreciable amounts of student time. There have been only a few demonstrations of slight improvements, none large enough to have any practical significance. Overall, this means that these innovations yield improvements in efficiency, i.e., cost, but <u>not</u> in effectiveness.

Innovations to training--based on what we know about these three examples--may have a potential for improved effectiveness, but this has not been conclusively demonstrated. Superior student achievement, compared to that with conventional instruction, was found in about one-third of the studies of computer-assisted instruction (CAI); the amounts of superiority were small. Two such results (out of 1? cases) were reported for the use of maintenance simulators; none for flight simulators. It is often said that maintenance simulators can provide better training because they can demonstrate a larger number of malfunctions than is possible with actual equipment trainers. This plausible claim has not been verified nor, apparently, even tested. Course materials and instructional procedures incorporated in innovations to training have essentially been modeled on the current methods. This imposes an unnecessary limitation on improvements in effectiveness that may well be present. The goal of almost all improvements to training so far examined seems to be equal effectiveness and savings in the cost of training; only lip service has been given to improved effectiveness. It appears possible to produce improvements in effectiveness if costs were kept constant, i.e., if large savings in cost were not also required at the same time.

Finally, there has been no attempt to look for trade-offs between cost and effectiveness. To do so would require different types of comparisons, different experimental designs, and a greater concern with improving training than is currently evident. It would require control (in experiments), over the amount of time students spend with simulators or CAI/CMI to determine the shape of the learning curve and thus the optimum time to go from simulator to the aircraft or actual equipment.

Additional practice in training brings diminishing improvements in performance. The well-known phenomenon of the learning curve and its impact on the cost-effectiveness of training has been almost totally disregarded except in one excellent study. Povenmire and Roscoe (1973) showed that the transfer effectiveness ratio, which measures the amount of flight time saved due to use of a simulator, continued to decrease and eventually became flat (after about 7 hours in this particular study where the task was for the pilot to qualify in a check flight). When the decreasing TERs were compared to the costs of using the simulator or aircraft in this case, it became clear that it would be more cost-effective to use the airplane rather than the simulator for additional training after about 4 hours in the simulator (and not after 7 or 11 hours, as was done for some of the test groups in this study).

A concern with trade-offs between cost and effectiveness would also require us, in effect, to develop simulators that differ in complexity, and therefore in cost, to see the extent to which effectiveness may change as a consequence of changes in the cost of equipment. Up to the present, all comparisons have been made with a simulator designed, more or less to an arbitrary level of complexity, as the result both of the Instructional System Design process and of negotiations between operators, trainers, and developers over requirements and costs. This process needs data on the critical relationship between cost and effectiveness in order to make optimum trade-offs.

CONCLUSIONS

Flight simulators, computer-based instruction and maintenance training simulators appear to be as effective as the methods of training they can replace; they also can reduce the costs of training. Thus, they appear to be cost-effective compared to more conventional methods of training. These new methods of training have not been demonstrated to be more effective than the older ones, although it is possible, if cost savings were not required or were kept constant, that they might be. Trade-offs between the effectiveness and cost of alternative training systems have not been performed. To do so, more reliable and more complete data on effectiveness and cost would be required in most areas of training.

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RAM AND SUPPORT CONSIDERATIONS IN ARMY TRAINING DEVICE DEVELOPMENT

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ABSTRACT

Although reliability, availability and maintainability (RAM) and system support policies for Army equipment in general are fairly well defined in such documents as AR 700-127 and AR 702-3 or various MIL STD's, there is little that recognizes unique RAM and support considerations that apply to training systems. The authors identify some of these considerations, which, though largely unique to training systems, are generic to most training systems. They then discuss the impact of these considerations, with emphasis on how RAM specification and growth and support management differ from that of the combat systems around whose needs AR 702-3 and the MIL STD's are principally modelled. The authors develop specific conclusions as to policy and practice distinctions from the combat systems model that should be made in training systems development programs.

INTRODUCTION

The subject of this paper is one that is perhaps as much a cause of frustration, and a cost driver, as any in the field of materiel acquisition management. On the face of it, it wouldn't seem that it should be. The acronym "RAM", Reliability, Availability, Maintainability, can be re-arranged to make a very simple mathematical statement

$$A = f(R, M)$$

that availability of a system is a function of reliability — how often it fails — and maintainability — how much time it takes to fix it and keep it operating. The implementation of this relationship does not seem much more difficult. The customer presumably knows what availability he will require. Volumes of data exist on the reliability of almost any class of components. The mathematics of reliability calculations are not unusually difficult, and engineering to enhance maintainability is generally well documented. So, is it really necessary for this almost trivially simple seeming relationship to cause so much heartache and cost so much money?

The answer, of course, is that it is necessary only to the extent that we accept Murphy's Law as an inviolable rule of nature. In our more rational moments, as when we are contemplating someone elses' problems, we know Murphy's Law to be mostly a consequence of human carelessness and poor judgement. We are, then, led to a conclusion that most RAM fiascos, as most other manifestations of Murphy's Law, can be avoided by using more care and better judgement.

Recognizing that that last piece of advice, left standing alone, is not particularly useful, the Army has created a substantial body of regulations, standards and methodology to guide our judgement and prompt our memories. This has evolved over many years and, in our opinion, when applied to types of systems with which the Army has had extensive experience, represents an excellent prescription for achieving the required level of reliability, availability and maintainability within a stated cost and time. Indeed, we would suggest that most failures of RAM programs in conventional military hardware development have occurred when the developers put their RAM engineering emphasis in areas with minimum payback and tried to take shortcuts in some of the important ones. As the hobbit, Bilbo Baggins, observed "Shortcuts make for long delays". This is particularly true if the short cuts are in the wrong areas.

The previous observation applies, of course, to systems where the paths have been trod before and the way has become well charted. Even with those systems, there was a period when delay and expense were incurred not due to any shortcutting, but just from being down on the learning curve. As we came up on the learning curve, the guidance could be formulated and then extended to other type systems, where, again there would be a learning period until the variations in the guidance applicable to the new type systems could be recognized.

The growth in recent years of complex major training simulation systems has presented us with the maturing of just such a set of altered RAM guidelines. We, the authors, have worked for the past several years in RAM development and management of these training devices within the general context of AR 702-3, the primary source for RAM development guidance in Army materiel acquisition programs. As with any good regulation, intelligent interpretations, weighing payoffs against cost and time, are possible, and we have made them, and seen them made, some more successfully than others. With our share of bruises from climbing up the learning curve, we feel we can now speak with some authority on what these emerging guidelines are. The interesting aspect of this is that, as yet, the rest of the user and development community, to include RAM people, who have not yet had this experience naturally think in terms of the standard procedures and each new project and each new person coming into the project represents a new education effort. This conference is, therefore, a timely opportunity to get some of our ideas and experience before the training device community, discuss them, and suggest some steps for recognition of changes in RAM policy and procedure that will expedite development of adequately available and supportable training simulation systems.

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RAM REQUIREMENT DEFINITION

As we mentioned earlier, RAM performance is something that costs money and takes time. The users' bottom line is being able to count on the system when he needs it, for as long as he needs it. In saying this, it is important to understand what overstated RAM requirements mean to the developer and the logistician. The developer is committed to high reliability parts, heavily derated circuits, rigorous QA inspections and redundancy in mission essential functions. When the thing goes down, we can't take the time to isolate the failure to the piece part, nor to send for the technician and equipment that could, so we will replace the obviously failed major assembly and be back up in a few minutes. That the logistician is now stocking the supply system with these major assemblies, instead of just replacements for the failed parts, is something we have to decide to afford. The off-line time to repair the major assemblies has become a secondary consideration, way behind that on-line time to get the system back up.

With combat systems, when failure or unavailability can get people killed and battles lost, it is possible to justify some very expensive RAM requirements. In the Concept Formulation Phase of the Life Cycle Management Model (DA PM 11-25) a generic process for all Army materiel acquisition is spelled out for justification of requirements, to include RAM requirements. For this process to work properly, it must be carried out jointly by the user and the developer in three distinct and separate steps. First the user must determine, in profiles of all missions and a summary of all operational modes, just how the system will be used throughout its life. This Operational Mode Summary/Mission Profile document can then be used by the user and developer to jointly determine a realistic definition of just what will constitute a mission or system failure and define objective criteria for determining how incidents are to be classified. With the Operational Modes summary, Mission Profile (OMS/MP), and Failure Definition and Scoring Criteria (FD/SC) in hand, the user and developer can then jointly develop numerical RAM requirements that realistically relate operational readiness and mission success to acquisition cost and logistic supportability. The basis for these requirements is stated in a RAM Rationale Annex to the official requirements document used to establish the development program. The methodology for preparing this annex and therefore for arriving at the numerical values, is excellently stated in the joint TRADOC/DARCOM RAM Rationale Annex Handbook. Besides calling for the OMS/MP and FD/SC as input, this procedure also requires consideration of the RAM assumptions made in the user's Cost and Operational/Training Effectiveness Analysis (COEA/CTEA) and of the developer's best technical approach analysis performed in Concept Formulation. The user then performs an analysis to determine the minimum acceptable values that will permit the system to be useful to him. The developer determines the best operational capabilities that are inherent to the selected technical approach and attainable within the projected development program. Hopefully, these will differ by enough and in the proper direction, to permit initiation of a program with realistic cost and mission effective RAM program objectives.

It should be noted, in regard to reliability qualification testing, that recent changes to AR 702-3 and the joint OTEA/TRADOC/DARCOM baseline FD/SC extend operational failure chargability beyond contractor produced hardware to include Government furnished equipment and the total support system. This will significantly increase the number of items which can result in an unsatisfactory RAM report card. Training Device contractors should be aware of this important new change and thrust in the RAM area.

We said that we were going to discuss variations from the standard RAM procedures that we considered applicable to training devices, but, in this case, we find the generic model to be admirably applicable to training devices as it stands. The unique feature in this case is that the generic model does not get applied to training device requirements definition as often or as thoroughly as it should. The RAM requirements analysis is usually done quite thoroughly for major combat systems. After all, the Army cannot afford to either gold-plate or come up a loser on such highly visible projects. The analysis is usually performed, albeit sometimes somewhat perfunctorily, (e.g., rarely is a CTEA available in time to support preparation of the RAM Rationale Annex) on lesser systems, to include stand-alone or non-system derivative training devices. The problem really arises when the training package is included in the overall development program of a major system. Priority goes to definition of the RAM requirements of the major system itself and its key support equipment. There doesn't usually seem to be enough left over to get around to the training devices, at least in time for the statement of requirements to have any effect on the development program. What results is that the users wind up shaping their program around what they are going to get, instead of telling the developers what they need in order to run the program they want.

RELIABILITY PROGRAM TASKS

An essential reference in preparing or evaluating any reliability program is MIL-STD-785B. This contains descriptions and guidance on the use of the various reliability engineering, management and accounting tasks that may comprise the reliability program of any material acquisition program. This MIL-STD enables the developer to put together a reliability program optimized around the needs of his particular project, to include training devices. These tasks, and their recommended applicability to the major phases of a material acquisition program, are shown in Figure 1.

While these tasks are written with the objective of general applicability, there are a number of considerations that guide their selection and use in training device programs. Many of these will be touched on later in this paper. One aspect of training device procurement, however, cuts across a number of these tasks and should be pointed out in this discussion. This is the tendancy of a training device developer to use more commercially available major assemblies and less development from the piece part level of major assemblies unique to the system. Thus monitoring and controlling vendor supplied items is keyed more to performance of fewer, more complex items and less to inspection of a large number of smaller parts. Failure Reporting Analysis and Corrective Action Systems (FRACAS) and Failure Review Boards must deal with failures within these vendor assemblies that are not necessarily controllable by the developer. The analytical processes, Failure Modes Effects and Criticality Analysis (FMECA) and reliability modeling, allocation and prediction are facilitated, but also constrained by the predetermined characteristics of these fewer, larger assemblies. Reliability growth, which, as we shall see, needs help, can get it by taking advantage of the

APPLICATION MATRIX

TASK	TITLE	TASK TYPE	PROGRAM PHASE			
			CNCPT	VALID	FSED	PROD
101	RELIABILITY PROGRAM PLAN	MGT	S	S	G	G
102	MONITOR/CONTROL OF SUBCONTRACTORS AND SUPPLIERS	MGT	S	S	G	G
103	PROGRAM REVIEWS	MGT	S	S(2)	G(2)	G(2)
104	FAILURE REPORTING, ANALYSIS, AND CORRECTIVE ACTION SYSTEM (FRACAS)	ENG	NA	S	G	G
105	FAILURE REVIEW BOARD (FRB)	MGT	NA	S(2)	G	G
201	RELIABILITY MODELING	ENG	S	S(2)	G(2)	GC(2)
202	RELIABILITY ALLOCATIONS	ACC	S	G	G	GC
203	RELIABILITY PREDICTIONS	ACC	S	S(2)	G(2)	GC(2)
204	FAILURE MODES, EFFECTS, AND CRITICALITY ANALYSIS (FMECA)	ENG	S	S (1)(2)	G (1)(2)	GC (1)(2)
205	SNEAK CIRCUIT ANALYSIS (SCA)	ENG	NA	NA	G(1)	GC(1)
206	ELECTRONIC PARTS/CIRCUITS TOLERANCE ANALYSIS	ENG	NA	NA	G	GC
207	PARTS PROGRAM	ENG	S	S(2)(3)	G(2)	G(2)
208	RELIABILITY CRITICAL ITEMS	MGT	S(1)	S(1)	G	G
209	EFFECTS OF FUNCTIONAL TESTING, STORAGE, HANDLING, PACKAGING, TRANSPORTATION, AND MAINTENANCE	ENG	NA	S(1)	G	GC
301	ENVIRONMENTAL STRESS SCREENING (ESS)	ENG	NA	A	G	G
302	RELIABILITY DEVELOPMENT/GROWTH TESTING	ENG	NA	S(2)	G(2)	NA
303	RELIABILITY QUALIFICATION TEST (RQT) PROGRAM	ACC	NA	S(2)	G(2)	G(2)
304	PRODUCTION RELIABILITY ACCEPTANCE TEST (PRAT) PROGRAM	ACC	NA	NA	S	G(2)(3)

CODE DEFINITIONS

TASK TYPE:

ACC - RELIABILITY ACCOUNTING
ENG - RELIABILITY ENGINEERING
MGT - MANAGEMENT

PROGRAM PHASE:

S - SELECTIVELY APPLICABLE
G - GENERALLY APPLICABLE
GC - GENERALLY APPLICABLE TO DESIGN CHANGES ONLY
NA - NOT APPLICABLE
(1) - REQUIRES CONSIDERABLE INTERPRETATION OF INTENT TO BE COST EFFECTIVE
(2) - MIL-STD-785 IS NOT THE PRIMARY IMPLEMENTATION REQUIREMENT. OTHER MIL-STDS OR STATEMENT OF WORK REQUIREMENTS MUST BE INCLUDED TO DEFINE THE REQUIREMENTS.

FIGURE 1

demonstrated reliability within proven components. In summary, the reliability program for a training device must consider and take advantage of the reliability program previously carried out in major developed assemblies which the training device developer has generally greater latitude to use.

AVAILABILITY

An obvious difference between combat systems and training devices is that in controlling and scheduling the use of a combat system, one must concede some degree of initiative to the enemy and provide a great deal of flexibility to respond to unexpected requirements. A training manager, on the other hand, generally has to have complete control of his scheduling and rarely does he have to schedule equipment around the clock. Thus the typical availability requirement for a combat system is long periods of standby in readiness for immediate response in periods of short intense use. This leads to definition of operational availability in AR 702-3 in terms of total available time within a stated calendar period. Any particular calendar period of use of a training system, however, is going to include scheduled periods of downtime, i.e., periods when the system is not required to be available. Describing operational availability as in AR 702-3 results, therefore, in stating an availability requirement that does not, in fact, exist. PM TRADE and the Naval Training Equipment Center have developed and used for a number of years availability characteristics based on schedulled usage. An article in the Army Logistic Center's RAM/ILS Bulletin of November 1981 addresses this case and provides an operational availability definition that uses only the system's availability during the periods when it is required to be available. Publication in this bulletin has not had a significant impact on training device availability specification; however, we anticipate bringing the idea to the forefront in future documents in order that it will take a more meaningful place in training device availability considerations.

RISKS

Risks are the considerations which cause some failure modes to be more critical than others and reliability of some components to be more critical than others. In combat systems, these risks are generally those that lead to mission failure. Preventing mission failure is also, of course, a major objective of reliability engineering of training devices, too. We have, however, already observed that the generally less catastrophic consequences of failure of a training mission affect the level of reliability that we can justify paying for. There are, however, some risks that require more stringent control than does the combat system. No one wants a combat system to be unsafe for its crew, but the level of safety that is sought reflects the fact that the battlefield is an inherently dangerous place. By contrast, death or injury in the training environment are unacceptable. Combat is also rather hard on the natural environment, while preservation of the environment is always a major concern of the training manager. These two considerations frequently inhibit the use of combat systems in training and make training simulation necessary. For example, one of the reasons for turret maintenance trainers is to permit students to work on the drive, hydraulic and electrical systems without being exposed to the lethal levels of force, pressure and voltage that are present in the actual turret. Therefore, while one can perhaps settle for a lesser probability of mission success in a training device, reliability engineering must do its part to absolutely preclude injury or environmental damage, risks which are generally acceptable at some level in combat systems. A good FMECA and a FRACAS program are therefore no less necessary in the development of a training device. The determinants of criticality may, however, differ from like analyses and programs in developing a combat system.

ENVIRONMENTAL DESIGN CRITERIA

The combat system must work in whatever environment the combat takes place. Thus AR 70-38 and MIL-STD-810 prescribe some demanding and expensive environmental design criteria: heat, cold, humidity, dust, moisture, shock vibration, etc. The training system, of course, must work where the training takes place and, for some systems, such as the Multiple Integrated Laser Engagement System (MILES), that is essentially the same as the combat system being simulated. Many training simulators can, however, be used in a fully controlled environmental shelter, subject to movement only under administrative conditions and generally can live with the same environmental design criteria as are commercially applied to fixed, interior electronic equipment. Even those training devices that are used in the same environment as the combat systems can enjoy some measures of relief from at least the extreme environmental criteria imposed on the combat system. As we have previously observed, the training manager has control over when his equipment will be used in extreme climatic conditions, and also, only a relatively small proportion of training occurs under those conditions. This is in contrast with most combat systems, where any one item must be inherently capable of quick deployment and use to counter any threat. This suggests that the training device can be designed to criteria that are less demanding than those of the combat system, and a kit or modification procedure provided for those relatively infrequent and scheduled periods of use in more severe conditions. Thus, while the combat systems on which MILES is used were designed for use in the full range of the former AR 70-38 climatic categories, MILES was specified to only the intermediate categories 5 and 6.

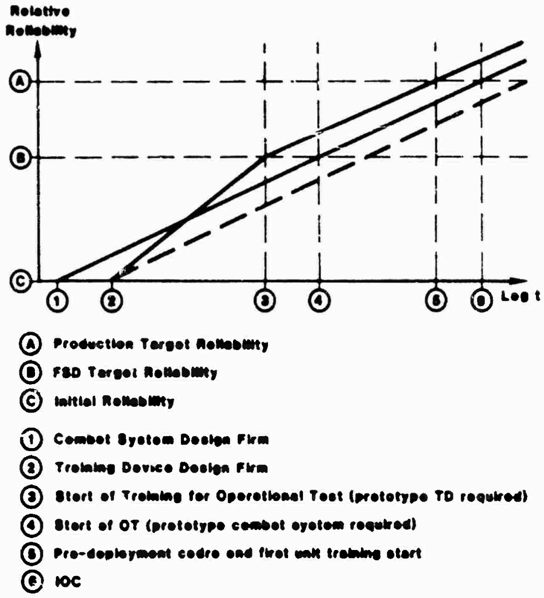
DURABILITY

The preceding discussion suggested a possible relaxing of standards for the severity of the use environment. Paradoxically, this paragraph is going to suggest that in the area of durability i.e., resistance to wearing out, what is adequate for the combat system may not be adequate for the training device. Consider that the gunnery controls of a tank are used only when that crew uses that tank in gunnery training or an engagement. It is very important that the controls work, but it probably isn't subject to very many use hours per year. Now consider the same controls in the Armor Unit Conduct-of-Fire Trainer. These will be used all day, every day by every crew in the battalion, probably more hours in a year than most tank controls will see in the life of the tank. Or consider an installation set of MILES equipment. Each unit scheduled to use it will come out, put it on their weapons, run the exercises, take the MILES gear off and, after restoring the weapons to inspection condition, replace them in the arms room. The MILES gear, on the other hand, will be inventoried, maybe get a quick check for serviceability, and be back out in the field with another unit the next week. Clearly use and wear out factors that determine the replacement and rebuild periods in the combat system must be reconsidered when the same component is used in the training device. Training systems that are of comparable durability and used on an hour-for-hour basis with combat system may in fact see a much shorter calendar life between replacement or rebuild. These are considerations that need not cause any problems if they are appreciated and dealt with in the life cycle support planning for the system, but they do cause some nasty surprises downstream if they are overlooked.

RAM GROWTH RATE

RAM growth management and projection are a normal part of any materiel development program and the methodology for doing this in training devices is not different from that of other comparable materiel. Several inherent characteristics of the development schedules for training devices do, however, have an interesting impact on training device RAM growth. First of all, design of a training device to simulate a combat system must unavoidably lag the design of the system. Changes after the system design is supposed to be firm will play crack-the-whip with the training device design. Thus the design effort on which the RAM growth is based starts later and suffers more rapid perturbation than does the design of the system itself. At the other end of the schedule lies operational test and evaluation of the system, which at least theoretically includes use of the operational training package to train test personnel. Evaluation of that package, to include devices, is one of the objectives of the OT&E. Thus the training device developmental period, in which the Army's Life Cycle Management Model concentrates most of the RAM growth of a system, is inherently truncated at both ends, as compared to that of the combat system, and perturbed in the middle.

Figure 2 shows the effect of this. In order to have a training device that can support the training package the device must be available, at its full scale development (FSD) reliability level, before the FSD prototype of the combat system, yet design cannot start until the combat system design is firm. Thus it has an inherently steeper growth rate than the combat system (and those are notoriously not conservative), yet it is a lower priority system. Not surprisingly, very few, if any, combat systems related training devices have ever met the schedule of their major combat system. What usually happens is shown by the dotted line, where the attainable growth rate causes the training device to reach the desired RAM goals at a later time than the combat system does. If the training device design can perform the necessary functions at the start of OT and pre-deployment training, this lag is not necessarily catastrophic, provided some realism has been employed in planning the initial training cycles. Specifically, that means that the attainable reliability in the prototypes that will be available in the early training cycle must be recognized and compensated for. For example, more intensive contractor support, rather than the test system support package, could be used to provide the required availability. This would also apply during the early cycles of post deployment training. The test program should be set up to provide realistic interim RAM goals during the formal test period, with follow on RAM growth and testing continuing until the fully matured RAM goals are met on an attainable schedule. The cost of more intensive contractor support or other measures to boost availability during the RAM maturation phase is not really an added expense; it is a recognition, before rather than after the fact, of a cost that is inherently there when procurement of the training simulator is tied to both the design and the schedule of a major combat system.



TRAINING DEVICE RELIABILITY GROWTH

FIGURE 2

SUPPORT CONCEPT

It is in the area of system support that some of the most significant differences between combat and training system use environments exists. Fundamental objectives of combat system support are to keep maintenance and repair of an item as far forward as possible and to minimize the skills and special equipment required forward to do it. A great deal of ingenuity has gone into meeting these two seemingly countervailing requirements, and the results, as noted in the introduction, are not inexpensive. The support system must also be fully transportable with the combat system, to include operating under combat conditions. An effect of this is that the support must be provided by uniformed personnel and the allowable tasks become constrained by the skills that can be taught in the military training context. It also means that support equipment must be transportable and operable under some very adverse conditions. It means that everything needed to operate and maintain the system must be available through the Army supply system. In summary, all the way back to its roots, the support system is, or can be, detached from civilian industrial or commercial resources.

Obviously, such extreme support measures apply to few if any training devices. Those that are placed in the TO&E of a tactical unit come closest to such support requirements. Such devices would require the totally transportable and Army contained support system. Since the training systems will inevitably have a lower priority than the unit's weapons, transportation and communications systems, it is most important that such a training device impose a minimum burden on the owning unit. This means no additional skills can be required. It means minimum maintenance, parts stockage or additional tools and test equipment. These conditions have generally limited TO&E training equipment to very simple devices.

The more common case, applicable to more complex devices in which the support requirements become more demanding, are those where the device is treated as part of the Post, Camp and Station property. It may, in fact, be on the property book of a tactical unit, but not as an item to be carried to the field and through combat with them. If the unit moves to another station, the trainer would be shipped administratively. Obviously, a lot more options are available for supporting a training system in this environment than in the full TO&E environment. It remains true that use and support of the device should not be a burden to the unit. Yet we are now dealing with devices that require some unique skills, training and logistic effort to use and support. We must obviously take advantage of the access to fixed facilities and civilian industrial skills that the garrison environment affords. Operator/organizational maintenance becomes reduced to simple GO-NO GO checks with turn-in to a central facility (or facility contact team) for any failed units. The trainee operator is not to be burdened with any additional learning in order to be able to use his training device. The central facility will therefore provide any unique operating skills that may be needed. This central facility, which can be either a contract operation or a Government industrial one, also equates to the DS/GS level in the combat system support model. It should, however, be able to effect significant economies over a field DS/GS operation due to its personnel stability and technical skills, access to fixed industrial facilities and commercial sources and the scheduled nature of training equipment use.

TYPE CLASSIFICATION

The environment in which the training device is used in a scheduled manner, at a given station and supported out of an industrial facility is, we have seen, a major departure from the one in which most type classified standard Army systems are used. The check list of plans, studies, tests, reports and evaluations by which the materiel acquisition decision process arrives at a type classification standard decision is necessary to insure that all elements of that transportable self-contained support system are in place and balanced with regard to each other. It goes far beyond merely ensuring that the performance of the system is adequate. It insures that all parts, tools, and test equipment are correctly entered in the Army supply system, all skills necessary to use and support the system are correctly identified, that stand-alone literature is in place, that everything is quantitatively distributed where and when it will be needed and can be moved as tactical or strategic exigencies may dictate.

No one would say that a garrison use training system should be put in place without adequate planning for its support, but some economies relative to the effort for a worldwide combat survivable support system may be attainable. Let us look at what is really required. The Government should require the contractor to develop and document a complete technical description, identify, describe and validate all maintenance and repair tasks, along with the skills, tools and written instructions to perform them, establish parts stockage and use rates and validate commercial transportability. These are the things the Government needs to set up its own industrial support operation or to "should cost" or compete a contractor support operation. They are still a far cry from MIL STD documentation, accession of all end items, parts and tool to the Army supply system, Army personnel and force structure realignments and school curriculum changes. Appreciable savings in cost and time have been realized when acceptance procedures for such training devices have recognized the differences in support environment from a standard combat system.

SUMMARY

We have seen that the Army's policies and procedure for defining and specifying RAM requirements and managing the attainment of those requirements are largely modelled around combat systems, though they contain the flexibility to adjust to other systems. The training system sometimes lacks priority, in competition with the combat system, to get a timely and adequate definition of its RAM requirements. There are also a number of differences in the use environment, development processes and support concept of training devices that require the application of that flexibility. Component and part vs. major assembly considerations effect the reliability program. Availability definitions need to take full advantage of the training managers greater control over how and when the device will be used and of regularly scheduled periods of downtime. Risks of mission failure that are unacceptable in a combat system must be balanced against cost in a training system. but risks of injury and environmental damage that can be traded for mission performance in a combat system become unacceptable in a training system. We can take advantage of the generally more benign and controllable environment in which training devices are used to relax some of the very severe environmental standards to which combat systems are built. On the other hand the more frequent use that training devices receive means that we must either build more durability into them or accept more frequent rebuild or replacement. We cannot expect the training device to achieve RAM maturity in the same growth pattern, relative to the decision points, that the combat system does, if we must inherently curtail and perturb its design and development period and assign it a lower priority. The training device has access to a much less expensive and laborious support concept than is necessary for combat systems. This, in turn, means that some (by no means, all) of the steps in justifying type classification standard of a combat system are not necessary for training systems.

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LOW COST AIRCREW TRAINING SYSTEMS

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ABSTRACT

Two prototype low-cost systems have been developed for air crew training. These systems provide instruction in cockpit procedures and various flight tasks at approximately one quarter the cost of conventional training approaches. Savings are estimated to be $1.5 million for one of the low-cost systems, a cockpit procedures trainer for the SH-3H aircraft; $3.2 million savings are estimated for the other low-cost system, a part task trainer for the EA-3B aircraft. This report discusses the cost-saving approaches and the acceptability and cost effectiveness associated with these two developments. Efforts to translate the low-cost approaches to several "follow-on" production systems are discussed. Research and development plans for further improving low-cost training technologies also are described.

INTRODUCTION

The military requires training systems that cost less than current systems and still perform at least as well. Costs to be saved include not just dollars, but also personnel, energy resources and time - time for system development, maintenance efforts and operator/instructor personnel.

Unnecessarily high training costs in any of these resource areas always have been undesirable. Nevertheless, for the most part, the training community received the resources they requested and used the resources to provide useful but excessively expensive training systems. High training costs are no longer just undesirable; they are intolerable. No longer are ample resources available for training. If military training is not as efficient as it can be, there will not be enough resources to go around, and the result will be reduced Navy effectiveness. Research and development (R&D) offers a possible solution to this problem by showing how to build more cost effective training systems. Such R&D should allow wider distribution of effective training systems in the Fleet, with consequent benefits to Naval operations.

In pursuit of this R&D solution, the ultimate goal of the R&D program discussed in this report is to improve the process for acquiring "low-cost" training systems, i.e., systems that are lower in cost (in all critical resource areas) than conventional systems, but no less effective. To achieve this goal, low-cost training systems are conceived, designed and developed, and then implemented and evaluated in operational settings. Efforts are made not only to describe the cost saving features of the R&D developments, but also to formulate general procedures and rationale for the design of additional and better low-cost systems.

Distinguishing features of this R&D are:

- Comprehensiveness - To assure that resources saved at one point are not paid back at another, this R&D is concerned with all phases in the life cycle of a training system, from conception through obsolescence.
- Operational Implementation - Heavy emphasis is given to urgent operational requirements for use of the products from these projects.
- Eclectic Approaches - A variety of diverse areas and methods (e.g., performance measurement, visual displays, instructional strategies, etc.) are employed in efforts to reduce training costs.
- Cost Reduction - The emphasis is on reducing the costs of training certain skills to a specified minimum level, as opposed to enhancing student performance (which, nevertheless, is expected as a side benefit) with associated increases in initial training costs.

In line with the project objective, beginning in 1978, two prototype low-cost aircrew training systems have been conceived, designed, and fabricated. Costs were $335,000 for a low-cost cockpit procedures trainer (LCCPT) for the SH-3H aircraft, and $800,000 for a low-cost part task trainer (LCPTT) for the EA-3B aircraft. These costs are approximately one-fourth that of comparable conventional training systems.* Table 1 shows, for each aircraft, the costs and designations of the low-cost and conventional trainers.

* The 75 percent savings attributed to the low-cost systems is a conservative estimate to allow for errors in estimating costs for the conventional trainers. The estimates were based on original system costs corrected for inflation and costs of similar, more recently developed trainers.

TABLE 1. COSTS FOR LOW COST AND CONVENTIONAL TRAINERS

Aircraft	Device	Cost
SH-3H	2C44 (Conventional CPT)**	$1,800,000
	2C62 (LCCPT)	$ 335,000
EA-3B	2F29 (Conventional OFT)***	$4,000,000
	2C63 (LCPTT)	$ 800,000

**CPT = Cockpit Procedures Trainer
***OFT = Operational Flight Trainer

The dollar amounts specified for the two low-cost systems do not include costs for Government furnished equipment (GFE). Although some GFE was used, GFE equipment, as opposed to simulated parts, was not considered necessary for training effectiveness. (In support of this, many of the components supplied by GFE in Device 2C63 were simulated in Device 2C62, with no apparent loss in training effectiveness.) The GFE that was used was included in the low-cost devices because it was available and desired by the Fleet Project Team.

GFE in Device 2C62 consisted only of the throttle quadrant, which was used instead of modifying a simulated throttle quadrant, which was originally provided with the trainer. All else was simulated. GFE for Device 2C63 included all panels and inactive switches, some active switches, throttle and throttle quadrant, yoke and rudder pedals. Simulated equipment consisted of some active switches, all instruments, all wiring and the shell. Additional costs for simulating the components which were provided for by the GFE are estimated at approximately $200,000 for Device 2C63 and $10,000 for Device 2C62. These costs were not included in the prices for the two low-cost devices because the prices given for the conventional trainers also do not reflect GFE costs. These unaccounted costs would be expected to be as great or greater for conventional systems than for the low-cost systems, because an effort was made to discourage use of GFE parts for the low-cost systems for purposes of the R&D project. The seventy-five percent savings claimed for the low-cost systems is valid, however, even if these additional GFE costs are added to the low-cost systems costs and not to those of the conventional trainers.

Development times for the low-cost systems range between one to two years versus two to four years required for conventional programs. Although not fully demonstrated yet, the modular and simpler low-cost design is expected to produce fewer maintenance problems, with reduced repair time and costs.

Additional life-cycle savings will be realized from less expensive facility requirements for low-cost systems. Also, instructor involvement with the training process has been reduced 34 percent in a preliminary effort, and further reductions in instructor time (along with improved trainee performance) are expected with improvements in device utilization procedures. This reduction saves personnel costs; but, more importantly, it allows greater utilization of the limited number of available instructors for other important tasks.

DESIGN CHARACTERISTICS AND CONCEPTS

Design Characteristics

The low-cost systems consist of: (1) Device 2C62 (see Figure 1), an LCCPT designed to provide training for all normal and emergency cockpit procedures as performed in the SH-3H helicopter; and (2) Device 2C63 (see Figure 2), an LCPTT constructed to train all normal and emergency procedures and many flight and navigation tasks required for the EA-3B aircraft.

Figure 1. Device 2C62 (LCCPT)

Figure 2. Device 2C63 (LCPTT)

Detailed descriptions of the two low-cost systems may be found in a generic specification.[1] The description that follows is intended to identify the general nature of the systems, their principal training features, and differences between them and conventionally designed, higher cost counterpart training systems.

General Nature. Each low-cost system has three major components: (1) the cockpit, with controls and displays representing those of the real aircraft; (2) the instructor/student station, providing a means for problem initiation, performance monitoring, data retrieval and computer programming; and (3) the computer system, which activates and coordinates all other systems of the trainer.

The simulated cockpits contain functional components which are similar to the aircraft in relative position, size, appearance, tactile and proprioceptive feel, and operating characteristics. Cockpit displays significant to training react to student actions in all important respects just as does the actual aircraft. Flight control feel is simulated only in Device 2C63 (yoke and rudder). Appropriate sound cues of the aircraft also are simulated. Nonfunctional mockups were used where functional components are not cost-effective. These mockups duplicate the corresponding components of the aircraft in appearance and location only. As described earlier, some Government furnished equipment was used.

Principal Training Features. The instructor/student station contains keyboard controls and CRT displays, and is located for convenient operation by an instructor. The controls and displays can be rotated into position for operation by a student instructor or for self-instruction. (For some training sessions, the instructors' normal interactions with trainees were replaced by allowing the trainee to practice procedures in the devices on his own or with the assistance of another trainee.) To set up a problem, one presses a key on the keyboard, which automatically creates displays which are appropriate for the procedure to be performed. The CRT lists cockpit controls that need to be repositioned manually before the procedure begins. When these controls are in proper positions for the procedure, the student attempts to perform the procedure in the usual manner through operations in the simulated cockpit. Approximately fifty normal and emergency NATOPS (Naval Air Training and Operating Procedures Standardization) procedures can be practiced in this way and over 100 individual aircraft malfunctions can be presented to the student in a similar fashion with each of the two low-cost systems.

To complete a Prestart Checklist Procedure, for example, the trainee performs the following steps: (1) complete "Preflight" operations; (2) check "Upper Fuel Caps/Sextant Cover/Spoilers Flaired"; (3) assure that "Cabin Circuit Breakers" are in; (4) assure that "LH or RH Fuel Boost Circuit Breakers" are in; and so on to the end of the procedure. Procedures vary in length from seven steps (e.g., a hydraulic failure) to thirty-two steps (for a start procedure) with many actions required for most steps.

Errors made during the execution of the procedures are indicated by displaying on the CRT or hard copy printout, the numbers and names of the procedural steps performed correctly, incorrectly or omitted by the trainee, in the order of their performance. The time for completing the procedure is indicated on the hard copy printout and the CRT.

To indicate a student's progress, a record of the performance of each student instructed on the system is shown for each procedure. These records include, e.g., the number of errors on the last four trials, total trials, etc. Cumulative totals are provided across a class to indicate group progress and to allow an individual to compare his performance with his classmates. Examples of these totals are: the number of trainees who attempted each procedure, the number of trainees who achieve criterion performance on each procedure, etc.

The LCPTT, in addition to all NATOPS cockpit procedures, allows training for normal and emergency flight tasks* as indicated in Table 2.

TABLE 2. FLIGHT TASKS TRAINED WITH THE LCPTT

- takeoffs	- takeoff/landing emergencies
- climbs	- flight control boost system failures
- turns	- run away trim
- cruise	- fuel management procedures
- descents	- TACAN and radio navigation
- approaches	- radio/communications procedures for crew coordination
- landings	- instructor simulated ground communication

* After completion of the training effectiveness evaluation, the LCCPT (Device 2C62) was modified in accordance with the instructors' requests to include limited flight capabilities. Altitude, speed and pitch simulation could be controlled with collective inputs. This provided a task for time-sharing practice with cockpit procedures, allowing trainees to learn to perform the procedures and control the aircraft, simultaneously.

Low-cost visual displays (developed in part under a different R&D project at this Human Factors Laboratory) complement instrument displays with schematic, computer generated imagery of carrier and field landings in the practice of flight tasks. A low-cost, torque-motor control loading system (adapted from a similar system developed by the Naval Air Test Center at Patuxent River) will soon be implemented in efforts to increase the fidelity of the "feel" of yoke and rudder control movements.

Differences with Conventional Systems. There are four major differences between the low-cost systems and their conventional counterparts: (1) the low-cost systems are lower fidelity devices with respect to some of their components and response characteristics (see next section for examples); that is, the physical similarity of the low-cost systems to the actual aircraft is less than is that of the conventional systems; (2) the low-cost systems include simulation of engine and other sounds associated with performance of the training tasks, whereas conventional CPT and part task trainer (PTT) systems include no sound simulation; (3) the design of the low-cost systems permits a limited self- and peer-instructional capability including computer aided problem set-up, and automatic scoring of student performance[2]; and (4) commercial standards were used for system parts and documentation.

Design Concepts

The design characteristics described in the foregoing, which are responsible for the noted cost savings, are the result of conscientious applications of rather pedestrian design concepts. Generally, the design concepts indicate that training systems should include: (a) only features essential for achieving the training objectives; and (b) instructional aids that facilitate the learning. Significant contributions to achievement of the low-cost goals are found in day-to-day implementations of the low-cost design concepts in the face of a variety of problems associated with computer automation and field settings.

Guidance for the application of the low-cost design concepts may be found in the previously referenced generic specification. More general and extended guidance is being developed in the forms of guidelines for performing the analyses that dictate the low-cost features.[3,4] Further guidance also is being initiated, with the support of the Office of Naval Research, in the forms of systematic approaches to help assure that particular characteristics of training systems, management procedures, procurement policies and organizational variables are maximally conducive to the design, acceptance and use of the training system. The importance of such guidance is especially important for innovative technology, as with low-cost systems, where the goal is cost effective training, rather than replication of some operational environment. Without such guidance, training programs are built in accordance with far less than the best of available technology, and desirable features of systems are not well utilized (see, e.g., Caro, Shellnut and Spears).[5]

Analyses were performed to include in the training system only the minimal features required to satisfy the training objectives. To accomplish this, discussions were held among Human Factors personnel, engineers and subject matter experts in which efforts were made to determine whether certain cost-saving features, as listed in Table 3, could be implemented for each training task, with no loss in training effectiveness. These analyses resulted in simulation fidelity levels that are lower than those of conventional systems.

TABLE 3. COST SAVING FIDELITY FEATURES

- Elimination of redundant capabilities
- Approximate (vice exact) cockpit dimensions
- Chairs vice aircraft-type seats
- Photographs vice panels
- Compressed instrument faces
- Restricted needle movements
- Discrete vice smooth needle movements
- Silk screen instrument faces
- Malfunctions that give onset cues but not progressive degradation
- Limited flight dynamics

In reference to Table 3, a malfunction needs to be simulated only with one engine if required operator responses to the same malfunction in the other engine are the same. Simulation of the various engine malfunctions would be distributed among all engines, however. This also applies to hydraulics, fuel tanks, generators, etc. The approximate cockpit dimensions of the low-cost systems were not noticeably different from more exact (and costly) constructions. Tasks could be learned as well using chairs instead of more expensive seats. In many cases, photographs of a panel were as useful as more realistic panels. Graduations on instrument faces could be compressed imperceptably and the full range of needle movement could be reduced for some tasks to help restrict needle movements to 270 degrees (allowing the use of a D'Arsonval meter movement rather than more expensive servo mechanisms). Discrete needle movements could be used instead of smooth movements, where the dynamics of the movement were not important cues for action. (Trainer cockpit indicators do not have to move as far or track in the identical manner as the aircraft indicators if these characteristics are not essential cues, as determined in discussions with subject matter experts, for the tasks to be learned.) Silk screening methods were less expensive than using real instrument faces. The simulation of a malfunction was terminated at a point where important cues for action are provided; all the effects of inappropriate actions are not provided. (For example, cues for an engine fire are simulated without including progressive degradation of the system that results from failure to correct the emergency.) Flight dynamics limited to 60 degrees for bank and 45 degrees for pitch saves money and still were sufficient to provide significant flight training. In these cases, higher fidelity would not contribute to greater training effectiveness; or at least, the contribution was not considered sufficient to justify the higher costs.

As with any training system, learning not achieved in the low-cost systems is accomplished with other media (e.g., classrooms, operational-flight trainers, aircraft, etc.) where the learning is more cost-effective. A trainee, for example, adjusts rapidly to the real panels of the aircraft when trained with pictures of panels that are not directly involved in the procedures to-be-learned; especially where, e.g., operational flight trainer (OFT) sessions with more realistic panels are involved. It is more cost effective to achieve the small amounts of learning associated with realistic panels in the OFT or aircraft, because the realistic or real panels are required in the systems for other critical functions. The learning, therefore, is accomplished with no additional development costs; and because the learning is rapid, increases in utilization costs (of the OFT or aircraft) are small.

Decisions regarding the design of "training aids" (e.g., automated performance monitoring, student performance records, assisted problem set-up, etc.) were based largely on their expected contributions to the: (a) operation of the training system; (b) cueing of appropriate trainee responses; and (c) provision of useful performance feedback to trainees and instructors.

This, generally, is the rationale for designing the training fidelity, defining the task components to-be-trained with various media and providing instructional and operating aids for the two prototype systems. The approach appears to be valid (see evaluation results in the following section) in the current applications. Details of the current approach need to be better documented and its cost effectiveness needs continually to be increased.

Approximately 50 percent of the noted savings in development costs is attributable to these "fidelity" analyses. The remaining 50 percent savings is due to the use of equipment and documentation that satisfy but do not exceed the requirements for administering the training and supporting the system. Commercial (vice military) parts and standards were employed to obtain approximately equal savings for less costly materials and less complex documentation.

ACCEPTABILITY AND COST-EFFECTIVENESS

Device 2C62 Evaluation

The acceptability and training effectiveness of the LCCPT under normal and modified conditions of use have been documented.[2] Information was obtained from two separate evaluations at two different operational sites (HS-1 and HS-10). Results from the first evaluation indicated that the LCCPT does what it was designed to do. The LCCPT allowed training of the same content, to the same level of proficiency, and with equal efficiency as the more expensive, conventionally designed counterpart device. The second evaluation demonstrated that, with proper utilization procedures, the role of the flight instructor when training with the device could be reduced.

The first evaluation consisted of a transfer-of-training experiment. Performances of trainees who were instructed on the low-cost device were compared with performances of trainees taught on the conventional device. The comparisons were made both in the trainers and in the aircraft.

A savings of $1.5 million was realized with the LCCPT on development costs alone ($335,000 cost for Device 2C62 versus $1.8 million cost for Device 2C44), and trainee performance in the trainers and aircraft was equivalent for the two systems. Table 4 shows the time required by trainees to achieve satisfactory performance in the aircraft and devices for the low-cost and conventionally trained groups. The hours-to-proficiency in the trainers and aircraft are in favor of (i.e., lower for) the low-cost device, but these differences do not approach statistical significance.

TABLE 4. TRAINING TIMES IN HOURS

	FLIGHT	
	Aircraft Training	Device Training
2C62 (LCCPT) Group		
Mean	15.58	14.33
S.D.	0.81	1.11
N	6	6
2C44 (Conventional CPT) Group		
Mean	16.68	15.81
S.D.	2.70	2.38
N	16	16
Mean Dif	1.10	1.48
t	0.97	1.45

The LCCPT required modifications to increase its simulation fidelity for a few of its components in order to be acceptable to instructors involved in the first evaluation. As described previously and indicated in Table 4, the lower fidelity levels appear not to have degraded critical task performance. In order to adapt to the lower fidelity of the new device, the instructors did modify their normal instructional methods. The instructors emphasized to the trainees operational cues that were missing in the device in order to achieve the high standards reflected in the evaluation results. This could account for the high student performance in spite of the lower device fidelity. This research demonstrates, at least for the procedures monitored, that instructors can use lower fidelity devices to achieve training results that are equal to those of higher fidelity devices. The LCCPT was modified to include significant changes recommended by the instructors prior to the second evaluation.

The instructors expressed confidence in the basic ability of the LCCPT. Additional validation of this opinion was a contribution of the second evaluation. The training conditions of the second evaluation were sufficiently different from those of the first evaluation to test the "robustness" of the LCCPT, i.e., its ability to continue to train as well under a variety of operational conditions.

Experimental data on a conventional training system were not obtainable for comparison with the LCCPT in the second evaluation. Therefore, a detailed comparison of performance of low-cost versus conventional devices, as was done in the prior evaluation, was not repeated. However, in the second evaluation, the LCCPT satisfied operational standards for trainee performance as a replacement for an Operational Flight Trainer (Device 2F64B) in syllabus sections that called for cockpit procedures training. All four trainees received satisfactory ratings in the LCCPT. Only one of the four trainees failed a procedure in the aircraft, a normal occurrence according to the instructors. This finding extends the finding from the first evaluation - that the LCCPT provides training for cockpit procedures that is the equal of a conventionally designed system - to another situation and another system. The similarity of results across the two situations helps to establish that the conclusion derived from the first evaluation concerning the high training effectiveness of the LCCPT does have general validity.

The second evaluation was conducted to determine whether the training effectiveness of the LCCPT as observed in the first evaluation could be extended to a situation wherein peer- and self-instruction are used to streamline the instructors' interactions with trainees. This evaluation showed that some of the relatively costly and much demanded instructor time could be redirected to other activities, with no apparent training detriment. A 34 percent reduction (10 hours for traditional approach versus 6.6 hours for low-cost approach) in the time instructors normally spend with trainees, was obtained. This reduction, however, was accompanied by a 166 percent increase (10 hours versus 26.6 hours) over previous syllabus schedules in the amount of time the device was used by trainees (student voluntary access to the device was unrestricted). The extent to which this tradeoff between decreases in instructor time and increases in device usage time is necessary with the current or any other approach is not known. Further, the extent to which this tradeoff may have undesirable effects (e.g., where device time is more scarce than instructor time) also is not known.

The LCCPT provided instruction for six additional trainees from two classes which immediately preceded the class from which the present data were obtained. The performances of trainees from these prior classes were not included in the foregoing analyses because the peer- and self-instruction conditions were not yet sufficiently implemented with these classes to test their efficacy. (The instructors needed to become more familiar with and confident about the new device and syllabus before integrating the peer- and self-instructional procedures into their training routines.) Thus, the data from these earlier classes do not reflect on the major experimental issue of evaluation two. These "pilot" data, however, do provide additional support for the basic effectiveness of the LCCPT. All trainees from these two earlier classes passed all tests in the trainer and in the aircraft; in fact, their ratings were quite similar to those of the third class--the class of major concern for the second evaluation. Mean performance ratings for trainees in these two prior classes were 3.05 and 3.06 in the LCCPT and 3.05 and 3.02 in the aircraft for the first and second classes, respectively. These ratings are comparable to ratings for the third, "experimental" class, i.e., 3.08 in the LCCPT and 3.02 in the aircraft. Thus, these "pilot" data are consistent with the conclusions derived from the other data presented in this report from both evaluations of Device 2C62.

Device 2C63 Evaluation

A $3.2 million savings ($4 million cost for a modern version of Device 2F29 versus $800,000 for Device 2C63) is estimated for development of the LCPTT relative to the costs for developing a conventional system to train the same skills. Although data on trainee performance still are not yet ready for analysis, the LCPTT has been providing training in the Fleet (at VAQ-33, Key West) since early in 1981 to the apparent satisfaction of trainees and instructors. In addition to evaluation of overall effectiveness, special efforts will be made to evaluate the contributions of the low-cost visual and control loader by comparing the training effectiveness of the LCPTT with and without a visual and with the control loading system versus a spring-loaded control system.

TRANSLATION OF BENEFITS

The products from these projects already have changed some long- and strongly-held beliefs and attitudes regarding training system design and use. Actions also are changing. First, the low-cost training systems developed under this R&D program have been adopted to provide "valuable priority training..." (HS-10 message of 19 Jan 82) in Fleet applications, in accordance with the experimental demonstrations. Second, the savings demonstrated for the two low-cost, R&D systems are being translated into similar savings for several production training systems; the costs of these production models represent significant breakthroughts in training system design. Of even greater significance, however, is the role these projects can play in opening the door for exploration of the much greater potential that the training technology field appears to offer.

The prime targets for current products are CPTs and PTTs developed by the Navy. Several "follow-on" trainers,* which are largely based on or significantly influenced by the current products, have been tasked for development by the NAVTRAEQUIPCEN, in addition to the two original prototype trainers. In addition to air crew trainers, one of the follow-on trainers will teach driving skills for an assault amphibious vehicle. The contribution these products can make to still other type trainers has not yet been determined. It appears, however, that significant contributions from current products can be made to a wide variety of trainers.

In addition, low-cost CPTs are being developed for commercial use by Appli-Mation, Inc., and American Air Lines for a variety of different aircraft, e.g., DC-8 (1 unit for Trans American Airlines); S-76 (1 unit for American Air Lines); 737 (3 units; for CPAIR, Gatwick Training Center and Southwest Airlines); 727 (2 units; for Mexicana Air Lines & Federal Express). These commercial training systems are based on the designs of the two prototype systems developed under the current projects and show similar cost savings. Similar to the two prototype systems, the costs of the commercial and the NAVTRAEQUIPCEN production low-cost developments are approximately 75 percent less than conventional counterparts with, in some cases, a decrease in required instructor time. Thus, the current project is responsible for an approach to training system design that in its ramifications apparently is markedly changing development practices, both in and out of the Navy.

* Production trainers under developement at the NAVTRAEQUIPCEN that are based on and/or heavily influenced by the products of this project include Devices 17A[illegible], 2C63A, 2C64, 2C61, 2C67, and a CPT for the EA-6B aircraft (device designation not yet known).

FUTURE PLANS

The current training systems are considered to be products of relatively conservative applications of low-cost approaches. (For example, video disc, computer generated imagery and computer assisted instruction technology might replace actual three-dimensional cockpit simulations.) Exploitation of this potential should involve definition and demonstrations of the most cost-effective combinations of fidelity designs and utilization procedures. Preliminary guidelines need to be completed for facilitating the application of low-cost approaches as well as the acceptance of the approaches and the products by the user community. Then, these guidelines need to be tested and improved. The desirability of incorporating the guidelines into an automated system developed at this laboratory for aiding in the process of instructional system design[6,7,8] needs to be investigated; and if desirable, the guidelines need to be incorporated.

The current training effectiveness evaluation for the LCPTT needs to be completed, and life-cycle data are needed on low-cost systems to assess cost-effectiveness over the life of the systems.

These and other efforts are needed to help assure that the advances made in the current program are not lost. Worse yet, the advances may become human factors and general training setbacks through misunderstandings and misuses of the new approaches. These dangers are quite real in that the "follow-on" production systems currently being developed are based in large part on the partially defined and sketchily documented low-cost approach. Training system development, in all forms, is a highly complex and creative process. The complexity and demands for creativity of relatively new approaches, such as the low-cost developments, are highly amplified, and will continue to be until more of the questions concerning low-cost approaches can be answered and more of the process becomes routine.

Enough justification for low-cost approaches has been provided by the current, and other, related investigations to encourage significant investments of R&D resources toward demonstrating and improving the technology and to recommend careful implementation of low-cost approaches in operational training programs.

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TACTICAL GROUND ATTACK: ON THE TRANSFER OF TRAINING FROM FLIGHT SIMULATOR TO OPERATIONAL RED FLAG RANGE EXERCISE

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ABSTRACT

A-10 pilots who rehearsed surface attack skills under high threat conditions in a flight simulator survived a significantly higher proportion of total RED FLAG missions than did pilots who did not receive the simulator training. These data support the notion that simulator training may have a significant influence upon aircrew survivability in high density ground threat environments.

INTRODUCTION

While several studies (Kellogg, Prather, and Castore, 1980; Hughes, Engel, and Lidderdale, 1981) have shown that it is possible to obtain significant improvements in both offensive and defensive skills under conditions of moderate to high threat density in a flight simulator, there exist no data to show that this improved performance transfers to the actual aircraft under realistic combat-like conditions. The present study clearly shows that, for the case of the A-10, training in the Advanced Simulator for Pilot Training (ASPT) can produce significant effects upon survivability in the operational environment. Furthermore, given the constraints of the present study, it might be assumed that the potential benefit of such training may be substantial indeed.

METHOD

SUBJECTS. Twenty-five experienced A-10 instructor pilots from Davis-Monthan AFB, AZ, served as subjects. Subjects had an average of over 700 hours in the A-10 and an average of approximately 1500 overall hours in fighter aircraft.

APPARATUS. The study was conducted on the A-10 configuration of the Advanced Simulator for Pilot Training (ASPT) located at the Operations Training Division of the Air Force Human Resources Laboratory, Williams AFB, AZ. Technical references for the device are found in Gum, Albery, and Basinger (1975) and in Rust (1975). Force cuing was provided through use of a g-suit. G-seat and platform motion cuing were not in effect. A monochromatic, computer generated visual scene of a tactical environment was presented via ASPT's seven cathode-ray tubes placed around the cockpit giving the pilot + 110 degrees to -40 degrees vertical cuing and ± 150 degrees of horizontal cuing.

PROCEDURE. Prior to participating in RED FLAG 82-2, eleven of the twenty-five pilots were trained in the ASPT. Following a brief familiarization period, during which time pilots gained practice in operating at low level in the A-10 configuration of the ASPT, each pilot received approximately two hours of practice on both close air support and battlefield interdiction missions.

Simulated close air support and battlefield interdiction missions were practiced in a simulated electronic warfare environment (see Figure 1). The threat array approximates that of a typical Soviet air-defense system at the Forward Edge of the Battle Area (FEBA). Field elevation of the environment was 5500 ft MSL. Temperature was modeled as 30 degrees Centigrade. Unlimited ceiling and visibility were in effect.

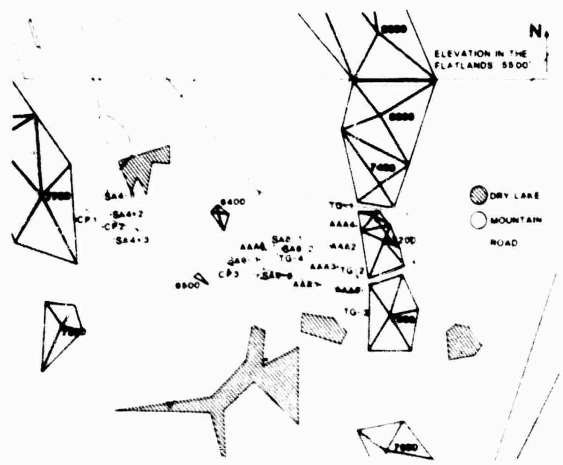

Figure 1. Simulated Hostile Environment

For the close air support (CAS) mission, target arrays in the simulator consisted of three groups of seven tanks each. Tanks were modeled to resemble the size and appearance of T-62s. Targets for the interdiction mission were the two command posts (CPs) located on the west side of the valley. Each command post consisted of a group of four vehicles. All elements in both the target and threat arrays were modeled as stationary vehicles/sites. Threat arrays consisted of ZSU-23-4 antiaircraft artillery guns, SA-8, SA-6, and SA-4 surface-to-air missiles. All threats were modeled to operate in an isolated (non-netted) mode and were modeled as radar controlled.

Following initialization from a point just outside the northernmost pass leading nto the target area, subjects were free to maneuver within the environment and to use whatever tactics they determined to be appropriate. No instruction or direction was provided as to what tactics to use. Prior to entering the environment, each subject was given a verbal "intel" briefing and a map showing the position of suspected threat sites. On each trial, or sortie, the simulated A-10 aircraft was loaded with 1200 rounds of 30mm gun ammunition. A capability to dispense chaff in a manual (as opposed to programmed) mode was provided. Upon the start of each trial, the simulator was reinitialized with the full weapons load described above.

Targets could be "killed" by hits of one or more rounds from the 30 mm gun (simulation of tracers as well as gun sound were provided). When killed, a target would momentarily disappear from the visual scene giving the pilot immediate feedback as to a hit. Although the target reappeared following the brief delay, subsequent hits on the target during a trial were no longer scored. Threat systems responded interactively to the aircraft in terms of the pilot's use of maneuver, direct terrain masking, chaff, etc. A "functional" simulation of a radar warning receiver (RWR) was also present in the simulator cockpit. The RWR symbology differentiated between SAMs and AAA, but did not provide specific symbology for the different types of SAM or AAA. Unclassified simulations of the auditory cues associated with threat status were provided through the pilot's headset. At the time of the study, there was no capability in ASPT for simulating the ALQ-119 electronic countermeasures pod (ECM).

Performance capabilities of the gun and missiles were modeled according to unclassified sources. Independent programs simulated the aerodynamic flyouts of each of the respective missiles. The aircraft was scored as having been killed if the missile passed within 50 ft of the aircraft. A visual image of the missile in flight appeared in the pilot's visual scene. However, no visual launch cues or in-flight smoke trail were associated with missile launches. Muzzle flashes, but no tracers, provided visual cues associated with the activity of the gun threat. In both cases, "kills" by the threat resulted in the immediate termination of the trial. Feedback was given the pilot in each instance as to the conditions of the kill. Terrain crashes also caused a trial to terminate.

Following simulator training in the ASPT, pilots trained in the simulator proceeded to Nellis AFB where they participated in RED FLAG 82-2. Six of these eleven pilots flew the exercise in A-10 aircraft equipped with the ALR-46 Radar Warning Receiver, the ALQ-119 ECM pod, and without a chaff dispensing capability. The remaining five pilots flew A-10 aircraft equipped with the ALR-69 Radar Warning Receiver, the ALQ-119 ECM pod, and <u>with</u> a chaff dispensing capability. Pilots in the non-simulator trained control group were evenly distributed between the two different aircraft configurations. Data from the RED FLAG exercise were collected on a noninterference basis. No changes or alterations to the scheduled range activities, scoring methods, etc., were made for the study.

RESULTS

<u>PRE-RED FLAG SIMULATOR TRAINING.</u> Although both interdiction and close air support were practiced in the simulator, the following data are for close air support only. In terms of survivability, pilots survived approximately 25 percent of the total sorties flown in the one hour of simulated, close air support training. Highly correlated with the percentage of sorties survived was the time each pilot was able to remain in the environment. There were no constraints forcing the pilot to maximize time in the environment. Pilots were free to exit the target area at will. On the average, pilots were able to remain in the environment for between two and three minutes. Since a "trial" was arbitrarily terminated at the end of four minutes, the brief duration of the average sortie indicates that most were terminated either by threat kills or by terrain crashes. Mean time between target kills was approximately 90-seconds with the probability of hitting a target being about 0.50.

Approximately two thirds of all gun engagements occurred at altitudes between 150 and 450 feet AGL at an average range of over 4000 feet from the target. Figure 2 shows aircraft position at the time it was destroyed by a threat in terms of altitude and range to the threat site.

Figure 2. Altitude and Range to Threat Site (± 1 s.d.) at Time Aircraft was Destroyed

The figure clearly shows that the majority of all kills were scored by the AAA. The frequency of kills by the AAA in the present simulator study closely matches that observed for the A-10 during the actual EWCAS exercise. The recorded frequency of kills by the SA-8 and SA-6 in the simulator were, on the other hand, low compared to the frequency of Class 1 miss distances recorded for these threats in the actual exercise. This is perhaps due to the 50 ft kill radius employed in the simulator and the 150 ft kill radius used to defined a Class 1 miss in the actual exercise. Figure 3 provides additional data on the bearing of the aircraft to the threat at the time the kill occurred in the simulator. These data clearly show that the aircraft was most often struck from behind.

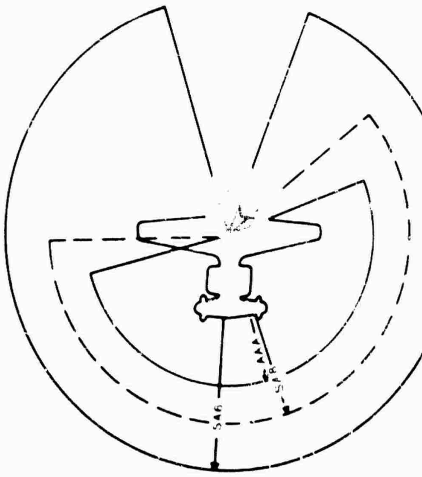

Figure 3. Bearing to Threat ($\pm$ 1 s.d.) at Time Aircraft was Destroyed

The improvement in performance that characterized one particular pilot over the course of simulator training is shown in Figure 4. The figure shows that following approximately 4-5 trials in the simulator, time in the environment (also significantly correlated with sorties survived) began to show a systematic increase. Figure 4 also shows, for these same trials, a steady decrease in the percent of total time the aircraft was within the AAA and SAM envelopes.

Equally as important as those sorties where the aircraft was killed by an air defense threat are those sorties which terminated with terrain crashes. The data in Table 1 show that, aside from the absolute number of crashes that occurred in the simulator, there was a clear increase in crashes as a function of pilot work load. To the extent that a simulator is unable to capture all the potential sources of work load present in the operational environment, these data provide insight into the extent to which the ground, itself, may constitute a significant threat.

EFFECTS OF SIMULATOR TRAINING ON SURVIVABILITY AT RED FLAG. Table 2 shows the percent of total RED FLAG sorties survived as a function of whether or not pilots received simulator training as well as the configuration of the A-10 aircraft flown during the exercise. These data are central to the transfer of training issue for flight simulators. Two clear findings are seen in the data of Table 2. First, those pilots who trained in a simulator configured like that of the aircraft flown during the

CONDITION	NOMINAL VALUE
• FIRING GUN DURING 10-SEC PRIOR TO CRASH	< 1 percent
• "STRAIGHT-AND-LEVEL" (less than 30° bank; less than 3g's; NO THREATS ACTIVE)	1 percent
• MANEUVERING (greater than 30° bank; greater than 3g's; NO ACTIVE THREAT)	4 percent
• MANEUVERING/ACTIVE THREAT/S	5 percent
• FIRING/MANEUVERING/ACTIVE THREAT/S	8 percent

CRASHES AS A PERCENTAGE OF TOTAL SORTIES FLOWN = 19 percent

Table 1. Terrain Crash Conditions

AIRCRAFT CONFIGURATION

CONDITION	ALR-46 ALQ-119 NO CHAFF	ALR-69 ALQ-119 CHAFF	OVERALL MEANS
NO SIM TRAINING	79%	75%	77%
WITH SIM TRAINING	58%	89%	74%
	68%	82%	

Table 2. Percent RED FLAG Sorties Survived as a Function of Aircraft Configuration and Presence/Absence of Simulator Training

subsequent RED FLAG exercise (i.e., ALR-69 and chaff) survived a significantly larger proportion of the total RED FLAG missions flown than did those pilots receiving no simulator training. This represents a clear positive transfer of training effect. The second finding shows equally as clearly that those who trained with the ALR-69 type RWR and chaff in the simulator and who subsequently performed under combat-like conditions in aircraft not having these capabilities, performed significantly poorer than their non-simulator trained counterparts. The effect of the ALQ-110 pod upon survivability was not addressed by the present experimental design. While aircraft configuration was not an intended manipulation of this study, it clearly shows the powerful effect of the simulator training upon subsequent operational performance. It also points to the need for training aircrews to operate under worst case, degraded conditions.

PILOT RESPONSES TO QUESTIONNAIRE ITEMS. An extensive questionnaire was completed by pilots following the RED FLAG exercise. A summary of their responses is contained in the following observations.

1. Pilots were uniformly critical of certain aspects of the simulator's visual system, specifically (a) difficulty of acquiring targets at extended ranges, and (b) lack of sufficient cues for flying low level without undue reliance upon cockpit instruments for altitude reference.

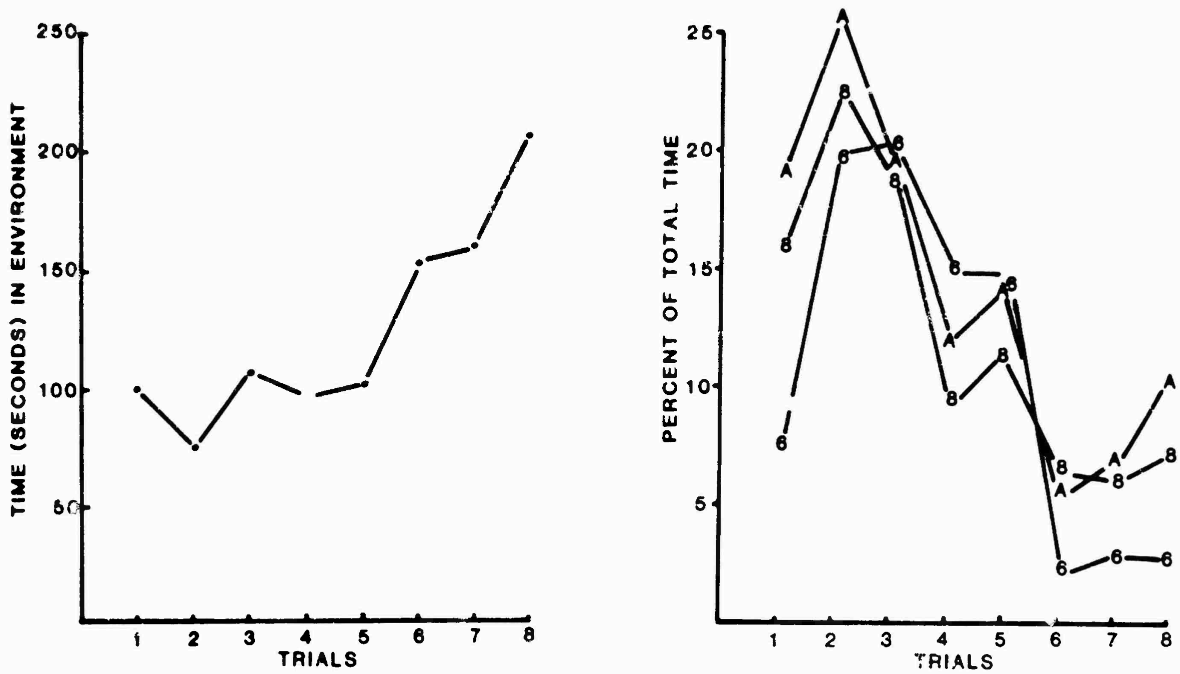

Figure 4. Time in Environment as a Function of Trials (Left Figure)
Percent Time in Threat Envelopes as a Function of Trials (Right Figure)

2. Pilots were in general agreement that the simulated hostile environment contained the critical cues found in the tactical close air support environment.

3. Pilots estimated that this type of simulator training might possibly improve the survivability of the current generation of A-10 pilots (i.e., those with little operational experience and no combat experience) by 20 percent on the average. There was a tendency toward more favorable estimates by those pilots having more overall fighter time and more experience in actual combat or combat-like situations.

CONCLUSIONS

1. These data provide empirical evidence that training under high density ground threat conditions in a flight simulator can improve the survivability of aircrews in a combat-like environment.

2. The fact that positive transfer of training was observed within the constraints of the present study (i.e., no formal training, per se; limited training time in simulator; no control over content or conduct of criterion RED FLAG exercise, etc.) suggests that the real magnitude of this transfer of training effect may be substantial indeed.

3. The occurrence of negative transfer for those simulator-trained crews who flew under no-chaff conditions in RED FLAG strongly indicates the need to train crews for operation under severely degraded or worst case conditions.

4. The unsystematic use of chaff and maneuver and the fact that the majority of all threats struck the aircraft from the rear suggest that serious training deficiencies exist in critical areas of electronic combat training.

5. The high incidence of terrain crashes has serious implications for those concerned with flight safety, especially under combat conditions. The present data suggest that the ground will present a formidable threat under the work load conditions of high threat, low level tactics.

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Evaluation of the Army Maintenance Training and Evaluation Simulation Systems (AMTESS)

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Abstract

AMTESS is the Army's attempt to develop an operational model and framework for acquiring modularized, generic simulation systems for maintenance training. More broadly, the AMTESS program is designed to lead toward a proven, systematized, institutionalized approach to task analysis, training requirements analysis, and fidelity analysis in support of training device acquisition. It is also designed to produce a model hardware configuration which includes a common two-dimensional display subsystem and a unique three dimensional hardware subsystem. Two prototype versions of the hardware model which vary along a number of significant dimensions (e.g., passive vs interactive use of video) are currently being evaluated for their transfer of training effectiveness at Aberdeen Proving Ground, Maryland. Transfer of training is being assessed on operational equipment using specially modified versions of current performance tests, versions designed to provide a rich, detailed data based. The data base will support assessments of overall prototype effectiveness as well as preliminary assessments of the effectiveness of specific prototype features. The results of these efforts will support initial implementation of AMTESS and at the same time will contribute towards a longer range objective of developing an operational model of device acquisition. In this paper, the AMTESS prototypes will be described, along with plans and procedures for their evaluations.

Introduction

The modern Army presently operates in an environment characterized by complex, sophisticated weapon systems with an increasing emphasis on support elements. In other words, the Army is faced with particular challenges in the area of systems maintenance. Major changes, therefore, are needed in maintenance training programs. In response to these changes and needs, the military community is responding by instituting a large scale infusion of training systems. One of these is the Army Maintenance Training and Evaluation System (AMTESS). The Program Manager for Training Devices (PM-TRADE) has been developing this system as a framework and a model for future procurements of maintenance trainers, designed to facilitate entry level training, as well as to sustain and evaluate skill levels in operational units. AMTESS is a modular system which combines two-dimensional displays (i.e., CRT, rear screen projection) with three-dimensional, dynamic equipment mock-ups, all linked to a core computer.

The Army Research Institute (ARI) has been supporting the PM-TRADE in this evaluation of alternative AMTESS prototypes (i.e., breadboards) produced by Grumman and Burtek/Seville, for training in the following MOSs: Self Propelled Artillery Mechanic (63D30) Hawk Firing Section mechanic (24C10) and Wheeled Vehicle Mechanic (63W10). Mini programs of instruction have been developed by Grumman for the 63D30 and 24C10, and by Seville for the 63W10 and 24C10. The purpose of the evaluation is to determine the relative, overall effectiveness of each prototype training system compared to training currently provided as well as to obtain student and instructor reactions. In this paper discussion will be limited to the evaluation for the 63D30 and 63W10 specialities.

AMTESS was envisioned as a means of applying advance simulation technology to a family of "hands-on," "heads-on," low cost, self-paced maintenance trainers for use at installation and unit levels. The AMTESS concept was a system to include: (1) actual "hands-on" maintenance performance training for specific maintenance tasks; (2) integration with existing training programs; and (3) a reduction in cost of ownership, or life cycle cost, for both acquisition and sustained operations.

Requirements

To meet the objectives of AMTESS, four separate tasks were conducted.

1. A Task Commonality Analysis to provide the basis for selecting representative tasks within the automotive maintenance specialities, for use in training system design.

2. A Training Requirements Analysis to develop a mini program of instruction for use in evaluation of AMTESS and to demonstrate the feasibility of integrating the concept into existing Army maintenance training programs.

3. A Fidelity Requirements Analysis to determine the fidelity requirements in a training system.

4. A design effort to develop the concept for AMTESS and to define a preliminary systems engineering design (PSED) for that concept.

Equipment

BURTEK/SEVILLE - WHEEL VEHICLE MECHANIC (63W10)

Based on the above analyses, Burtek/Seville Corporation developed a breadboard model for training specific tasks in the Wheel Vehicle Mechanic (i.e., 63W10) speciality. This system:

- requires a trainee to use and follow (i.e., perform) the activities presented in the technical manuals designated for the selected maintenance tasks.

- permits a trainee to practice maintenance tasks and obtain feedback on performance without instructor supervision.

- accommodates new training materials by software changes and appropriate preparation of new 35mm slides.

- can be adapted to a wide range of MOSs through fabrication of appropriate dynamic equipment mock-ups.

- includes a high physical and functional fidelity equipment mock-up.

GENERAL SYSTEM DESCRIPTION - Burtek/Seville[3]

The Burtek/Seville system includes a student station with CRT, rear projection screen (35mm slide projection), function keyboard and a dynamic equipment mock-up (Cummins Engine). These elements are linked to an instructor's station (CRT, keyboard, printer) through a 16-bit, 32,000 word microprocessor.

Trainees are introduced to particular exercises by the CRT, which then refers them to standard training manuals for detailed procedures. The rear projection screen is used to portray detailed photographs of the Cummins engine with indications of locations where maintenance is to be performed. The bulk of the actual instruction therefore is conducted through hard copy, media (i.e., the TMs and 35mm slides). The CRT does, however, play a critical feedback role since incorrect actions on the Cummins or on the student's response panel (for some simulated actions) are indicated on the CRT.

The instructor station includes the controls and indicators necessary to manage the program of instruction which is delivered at the student station. A video terminal presents information to the instructor, facilitating selection of training problems, selection of systems failures, and malfunctions, and presents records of trainee performance.

Training Management Programs

Programs. The following programs are provided to guide the student through maintenance procedures listed in his technical manuals, provide exercises in trouble shooting, and to monitor his performance:

- Training Exercise Programs
- Failure and Malfunction Programs
- Performance Monitoring Program

Training Exercise Programs. Training exercise programs are provided for the automative maintenance training activities. These programs permit the instructor to initialize particular lessons, introduce the trainee to the lesson, monitor specific steps and their sequence listed in the applicable maintenance TMs for the tasks being performed, and provide feedback to the trainee.

Failure and Malfunction Programs. These programs control failure and malfunction for the system being simulated. They remain in effect until corrected by the trainee or removed by the instructor. The malfunctions affect the performance of the engine components and provide appropriate cues and indicators for the trainee to isolate and identify the faulty component.

Performance Monitoring. This program provides monitoring, sensing and recording of performance errors of procedural steps related to specific tasks included in the simulator. Procedural errors are identified, recorded, and made available to the instructor on CRT or hard copy in an English language text that does not require analysis or interpretation. All performance activities are recorded and recallable by the instructor at the instructor station controls.

Grumman-Self Propelled Artillery Mechanic (63D30)

Conducting an analysis similar to those conducted by Seville/Burtek, Grumman Corporation developed a breadboard model for training specific tasks in the Self Propelled Artillery Mechanic (i.e., 63D30) specialty. This system:

- requires a trainee to use and follow (i.e., perform) the activities presented in the technical manuals designated for the selected maintenance tasks. However, more use is made of tutorial instruction in the Grumman system than in the Seville/Burtek system. The Grumman system employs color video and videodiscs to present explanations and demonstrations, both written and spoken, of how to carry out specific maintenance steps.

- accomodates new training materials by software changes, preparation of new videodisc materials.

- can be adapted to a wide range of MOSs through fabrication of appropriate simulated equipment components.

- includes high physical and functional equipment component work-ups. However, components are arranged in test bench fashion, and do not replicate the arrangement on operational equipment.

General System Description--Grumman

The Grumman system includes a student station with a color CRT, CRT touch panel and dynamic equipment components, arranged in test-bench fashion. These elements are linked to an instructor station (CRT, keyboard, printer) through a Motorola 68000 microprocessor. Programs and instructional materials are stored on floppy and videodiscs.

Trainees are led through lesson materials by the color CRT which gives instructions to consult specific pages in the appropriate technical manuals, short explanations on maintenance procedures and diagnostic questions. Explanations are either written or spoken and are supplemented by diagrams or video demonstrations of how to perform specific maintenance tasks. The trainee makes his responses either by touching a menu line on his CRT or performing some action on one of the three-dimensional mock-up components.

Training Management Programs

The information provided for Seville/Burtek is applicable to the Grumman System as well.

Subjects and Design

Subjects were chosen from two locations, the Wheeled Vehicle Maintenance School, in the Edgewood Area of Aberdeen Proving Ground (APG) for the 63W10 MOS and the Ordnance School in APG for the 63D30 MOS. Because of a recent change in the training program it was decided to add additional subjects from the Organizational Maintenance Supervisor (63B30) training program, also at Edgewood Area. A total of 120 subjects were included in the evaluation, with 60 subjects (i.e., 20 in each MOS, 63W10, 63D30, 63B30) assigned to the experimental groups (i.e., training included the AMTESS devices) and 60 subjects assigned to the control groups (i.e., conventional training without AMTESS devices).

An analysis of variance will be conducted,* using the results of a performance test conducted for this study. The dependent variables are number of items (i.e., skills) completed successfully (i.e., measured by number of GO's) and amount of time to complete the tasks and subtasks. An analysis of variance will be conducted using the data collected in the following design (see figure 1, below).

		GROUPS			
		EXPERIMENTAL		CONTROL	
Device	MOS	Average No. of GO's	Time	Average No. of GO's	Time
Grumman	63D30				
Burtek/ Seville	63W10 63B30				

Figure 1: Evaluation Design for AMTESS

Measures

The performance measures typically used in school programs have been expanded to allow for more detailed data collection. In addition to the performance and time measures collected, student, instructor and course developer questionnaires on each task will also be administered and reported.

Performance data will be restricted to those tasks which can be performed on the actual equipment within time and safety constraints. These data will consist of a series of go-no go decisions in a check-list format derived from the appropriate technical manuals for each task. Opinion or user reaction data will also be collected from students and instructors upon completion of training on the devices. In addition, questionnaire data will be collected from instructors and course developers regarding those tasks which can not be observed on the actual equipment because of time or safety considerations. Instructors and course developers will be presented with the entire mini-POI's in order to obtain training efficiency data. This evaluation will also include their reactions to determine if:

- tasks on each device are also taught in conventional training

- each of the tasks are necessary

- each device instructs each task to acceptable levels.

Evaluation Questions

With the evaluation design constructed in the above manner the following evaluation questions are anticipated to be answered by using various subsets of the data.

1. Does a simulator facilitate performance more than conventional instruction? (data used: the average number of GO's and time for all the experimental subjects versus all the control subjects).**

2. Does a simulator reduce performance time in relation to conventional training (data used: average time for all experimental subjects versus all the control subjects).**

3. Is there greater transfer of training using a simulator than that resulting from conventional training? (data used: average number of GO's for the experimental subjects minus the average number of GO's for the control subjects, divided by average number of GO's for the control subjects).

4. Is there a relation between instructor's and students' opinion about the training devices and students' performance? (data used: instructor and student questionnaire results will be correlated with average number of GO's for the experimental subjects only).**

The above questions were designed to provide insight into the overall effectiveness of the AMTESS devices. The same questions and data indicated will be analyzed for each MOS separately. Because of commonality of the tasks for both experimental and control groups in each MOS generalization of findings is more likely. Restrictions in generalization, therefore, will be a function of the reliability, validity of the performance measures, sample size, etc.

Procedures

All students, regardless of MOS, receive conventional training. Those students selected to receive simulator training (i.e., on AMTESS devices) however, will be directed to their respective training device prior to conventional instruction on the tasks used in this evaluation. The control group will continue with the conventional training and be tested in the same manner as the experimental group (i.e., on the actual equipment). The experimental group upon having conventional training will receive instruction on the device designed to teach skills they have not received before. Both groups will then be tested on the same skills on the actual equipment. The only difference, therefore, between the experimental and control groups will be the use of the training device for the experimental group.

* Complete data has not been collected at the time this paper was prepared, it is assumed, however, all data will be collected and analyzed for the Presentation in November. The remainder of this paper will present the anticipated evaluation which will be presented at the conference.

** Generalization of these findings must be limited because of differences in tasks across MOSs.

Instruction on the AMTESS devices will be conducted by one of the school instructors. The following tasks were selected for this evaluation.

63W10

- o Troubleshoot Engine Malfunction
- o Oil Pump Filter and Pump Removal
- o Oil Pump Filter and Pump Replacement

63B30

- o Adjust Alternator or Drive Belts
- o Starter Motor Removal and Replacement
- o Oil Pump Failure Troubleshooting
- o Inspect Electrical System

63D30

- o Starting System Problem
- o VTM Setup and Checkout
- o Defective Transmission Neutral Position Switch

Conclusion

AMTESS is conceptualized as a program designed to acquire Army training devices by systematic application of front end analyses.[3] The objectives of this program, as delineated by Hofer,[3] include:

o Development of maintenance trainers, utilizing a modular format, for development at both institutional and unit levels.

o Cost-effective assessment methodology development for Army Maintenance training programs.

o Development of Preliminary Engineering models (i.e., breadboard) to demonstrate the effectiveness and validity of the AMTESS concept.

The objectives and effort described here are envisioned to be an initial thrust in advancing Army maintenance training programs. It is recognized, however, that gaps in knowledge still remain to be filled. Example of such information shortcomings include:

- o Generalizability of findings
- o Specific Device Architecture
- o Incorporation of AMTESS into POI
- o Research on Measures of Effectiveness

Generalizability of findings to other instructional modules within the MOSs already under evaluation, to other MOSs, to other applications, such as use in organizational settings or use for skill qualification testing. At the very least, implementation of AMTESS for the MOSs under present evaluation will require the development of additional POI software modules. Software development for

AMTESS has proven to be extremely costly and time consuming, even for relatively minor changes in the prototype mini programs. Extension of program development to other portions of the MOS POIs should therefore be approached with great caution. It may not be necessary or even desireable to apply AMTESS to the entire POI. But in that case decisions must be made about what kinds and amounts of additional software development are needed. The proposed continuing ARI research would directly support this decision making.

Specific Device Architecture, (both software and hardware). This area would focus on such issues as: 2D vs 3D components within AMTESS; AMTESS vs flat panel devices such as (EC-3); and other features such as generalized troubleshooting instruction. The present AMTESS evaluation will not provide much information on the contribution of specific system architecture to training effectiveness. If the prototypes proved to be effective, therefore, specific sources of effectiveness are not likely to be understood. It may be that a relatively low cost feature of a particular prototype system is accounting for most of the training effectiveness and that some relatively high cost feature could be estimated. The converse may also be true, that is, the addition of a low cost feature could dramatically amplify the effectiveness of a particular prototype. For example, evidence is accumulating that generic troubleshooting training may dramatically increase training system effectiveness. Such training could be incorporated into AMTESS as a sub-routine and would lend itself well to presentation on satellite CRTs operating off an AMTESS main frame. This is just one of a number of features which would be studied in further ARI research under the AMTESS umbrella. Front end analysis methodology needs to be examined. Each of the Phase I contractors proposed different breadboard designs for the AMTESS program. A methodology is needed whereby the PM TRADE, TRADOC, and others can evaluate design specifications based on sound guidance for making hardware decisions. That is, there is general agreement in conducting job/task analyses and then training analyses in the development cycle for system acquisition. There is, however, little data on making the conceptual leap from these analyses to device characteristics decisions.

Incorporation of AMTESS into PCI. Design and use of AMTESS needs to be related to system variables, such as student characteristics, task characteristics, stage of training, use of other media, and time-based vs performance-based instruction. A number of very serious issues have already been alluded to. To date, for example, little or no analysis has been done on how AMTESS would be incorporated into ongoing POIs. For example, the Missile Maintenance Speciality has been converted from self-paced instruction to lock-step instruction. How will or should this change influence the way in which AMTESS is used? Student flow is yet another issue to be considered in defining appropriate uses of AMTESS. It was emphasized repeatedly at the last Interservice/Industry Conference that high technology solutions to training which do not cope realistically with student flow are not very useful to the military. The anticipated continuing research program will address the utilization issue in a major way and support both near and long term implementation of AMTESS through recommendations to PM TRADE and the TRADOC on how to effectively incorporate AMTESS into ongoing POIs.

Research on Other Measures of Effectiveness such as transfer of training to organizational settings, effectiveness in training "hot" panel repair, and use of analytic tools such as the TRAINVICE model.[4] The current AMTESS evaluation involves measurement of transfer effectiveness within institutional settings. The impact of AMTESS training or transfer of training to job sites will remain unknown.

The present evaluation of the Burtek/Seville and Grumman breadboards is an effort at meeting the AMTESS objectives. Other projects are planned of AMTESS prototypes or in progress which will support this program. A similar evaluation, for example, is under way in HAWK missile maintenance training. At the Air Defense School in Fort Bliss, an evaluation team is already on site collecting data. A supporting program of basic research is under way at ARI, in which the effects of simulation fidelity upon training effectiveness is being explored. This program is described in another presentation at this conference (Hays, 1982). While these activities represent considerable effort and progress in meeting the AMTESS goals, these must be extended further.

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ARI's Research Program to Determine Training Simulator Characteristics

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Abstract

The Army Research Institute for the Behavioral and Social Sciences (ARI) is developing a data base or the relationship between training simulator charateristics - in particular fidelity - and training effectiveness. In order to guide and organize the collection of empirical data for the data base, a two factor definition of simulator fidelity was chosen. The definition was limited to physical and functional similarity to the actual equipment. Several research efforts, using this definition, are currently being conducted or have just reached completion. This paper presents the results, to date, of completed research efforts, the anticipated results of ongoing efforts, and plans for future efforts. The goal of these efforts is to produce a data base which may serve as the foundation for the development of systematic guidance to support the specification of training device characteristics.

Introduction

The Army, the other services and the training community lack specific guidance to determine the characteristics which will enable training simulators to provide effective training at affordable costs. In the past it has too often been the case that the characteristics of a training device or simulator were determined by a mix of intuition (what someone thinks the device should be like) and cost (buy as much "realism" as we can afford). This approach to training simulator design is no longer a viable option given budget and other resource constraints. Accordingly ARI has undertaken a program of research to develop user oriented, empirically based guidance to aid in determining the characteristics of training simulators which will maximize training effectiveness. The program, from its conceptual development stage, through two ongoing empirical efforts and finally to its future goals, is summarized in this paper.

Defining Training Simulator Fidelity

The first step in developing ARI's training simulator research program was to adopt a working definition of simulator fidelity. An extensive literature search(4) indicated a large amount of inconsistency in how fidelity has been defined by the training R&D community. In particular, the term has been used somewhat indiscriminantly to label different categories of independent and depent variables which characterize both training systems and trainees. It was concluded that a limited, parsimonious definition of fidelity would best serve the compilation of a data base on how device characteristics are related to training effectiveness. Accordingly, the following definition was chosen:

> Training Simulator Fidelity is the degree of similarity between the training simulator and the equipment which is simulated. It is a two dimensional measurement of this similarity in terms of:
>
> 1) The physical characteristics of the training simulator.
>
> 2) The functional characteristics (i.e., the informational or stimulus and response options) of the simulated equipment.(2)

It was further determined that for purposes of empirically testing and validating this definition as well as for generating empirical data on the relationship of training simulator fidelity to training effectiveness, a three level ordinal scale would be used for each aspect of fidelity (physical and functional). This approach yields the matrix like the one in Figure 1. This nine cell matrix serves as the "basic" experimental design for use in subsequent empirical efforts.

Functional Similarity \ Physical Similarity	High	Medium	Low
High	HH	HM	HL
Medium	MH	MM	ML
Low	LH	LM	LL

Figure 1: Nine cell Matrix for Training Simulator Fidelity Experiments

Descriptions of possible devices which

would fit into each cell of Figure 1 may clarify this research approach. Cell HH: The actual equipment could serve as the exemplar of a high physical-high functional device and would therefore fit into the high-high cell of Figure 1. Cell HM: The high functional-medium physical cell could contain a fully functional device but one with some combination of reduced size, number and accuracy of its components relative to the actual equipment. Cell HL: The high functional-low physical cell could contain a computer graphics type device. This device would consist of interactive computer graphics which would function in an analagous manner to the actual equipment but which would look like line drawings. Cell MH: The medium functional-high physical cell could contain a partially disabled actual device. In this case, the device would look exactly like the actual equipment, but would be only marginally functional. Cell MM: A medium functional-medium physical device could be both partially functional and also be degraded in terms of size, number and accuracy of components as in cell HM. Cell ML: The medium functional-low physical cell could contain a device which consists of a two-dimentional display (line drawings) of the actual equipment. These drawings would afford the trainee a means for indicating control choices or test points, but would not provide complete system responses to those choices. Cell LH: The device in the low functional- high physical cell could be a totally disabled piece of actual equipment. Controls would be frozen, displays and test points would be non functional. The device would look just like the actual equipment but would not work at all. Cell LM: The low functional-medium physical device could be a totally disabled version of the degraded device used in cell MM. Cell LL: Finally, the low functional-low physical cell could contain a device which consists of a set of line drawings. These drawings would be physically the same as those in cells HL and ML, but would be totally non functional. These examples are not the only way the nine cell matrix could be filled, but they are one concetualization which ARI hopes will be fillowed by others. The idea is to apply as many alternate approaches to the question of physical and functional device characteristics and transfer of training as possible, but always trying to maintain the nine cell matrix as an organizational framework.

The goal of the empirical efforts in this research program is to provide data on the relationship of training device characteristics (fidelity) to training effectiveness as that relationship is modified by the many training system variables which interact with fidelity. Previous research efforts has not attempted to systematically control these interactive variables but hav rather looked at whole devices in the context of already established training programs. ARI believes that it is only by conducting controled, systematic experiments will we be able to generate the necessary data to provide useful guidance to individuals who must specify the characteristics of training devices and programs of instruction.

Table 1 displays a list of some of the variables which are believed to be those which

TABLE 1

Variables Which Interact With Fidelity

1. Task Type
   - Operations
   - Maintenance
   - Others
2. Task Difficulty
3. Specific Skills
   - Motor
   - Perceptual
   - Cognitive
   - Others
4. Trainee Sophistication
   - Novice
   - Intermediate
   - Expert
5. Stage of Training
   - Introduction
   - Procedural Training
   - Familiarization Training
   - Transition Training
6. Training Context
   - Institutional
   - Field
7. Incorporation of Device into POI
8. User Acceptance
   - Instructors
   - Students
9. Use of Instructional Features

interact with fidelity. ARI's goal is to accumulate data on all of these interactions (including data from previous experiments and experiments conducted by other research organizations) into a data base which can then serve as the basis for user oriented guidance in specifying the characteristics of a training simulator. The first of ARI's empirical efforts examined how physical and functional fidelity were related to training effectiveness in a perceptual motor task.

Simulator Fidelity in a Perceptual Motor Task

Honeywell SRC, under contract to ARI, conducted an experiment to determine (1) adequacy of ARI's definition of simulator fidelity, (2) the appropriateness of a nine cell physical-functional fidelity matrix, and (3) the relationship of simulator fidelity to training effectiveness in a perceptual motor task. Baum et al.[1] discussed the criteria used to determine the task selected in this experiment.

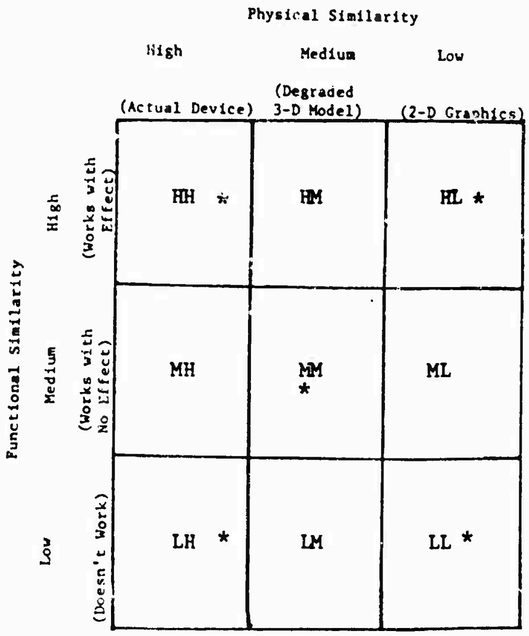
1. The task must embody the skills required in an actual maintenance task environment.

2. Task performance must lend itself to straight forward measurement; the measuremetns must be valid, reliable, and sensitive.

3. The task must be learnable in a reasonable period of time.

Based on these criteria the task chosen for this experiment was the truing of a bicycle wheel.

The wheel truing experiment used the fidelity definition and 9 cell matrix discused above. In this effort, only 5 of the nine cells were investigated. Figure 2 shows the nine cell matrix with the relevant cells indicated. By comparing the results in cells HH, MM, and LL the general relationship of fidelity (both physical and functional) to training effectiveness was determined. By comparing cells HH, HL, LH, and LL an indication of the relative contributions of the physical and functional aspects of fidelity was determined.



*Devices in these cells are included in the perceptual/motor experiment

Figure 2: Application of the nine cell matrix in the perceptual/motor experiment

The data collection portion of the wheel truing experiment was completed in June of 1982. Detailed analyses of the data are not available at the time of this writing, but tentative results can be presented. Overall, there was an improvement in trainee performance under all training conditions. Ten t-tests were computed which compared the starting and finishing points in each performance trial. Performance showed significant improvement (p less than .005) in all conditions.

In one analysis, the combined effects of physical and functional similarity on training effectiveness were assessed. A one way analysis of variance (ANOVA) was used to compare the performance, on actual equipment, of subjects trained on the devices in cells HH, MM, and LL of Figure 2. In this analysis subjects trained in the lower fidelity conditions performed almost as well as subjects trained in the high fidelity condition. There was in fact no statistically significant difference between these groups. The indication is therefore that training devices for a simple perceptual motor task may not necessarily need to be designed with high fidelity.

Another analysis attempts to separate the effects of the physical and the functional aspects of fidelity. This analysis compares the performance of subjects trained on devices in cells HH, HL, LH, and LL of Figure 2. When these data are analyzed using a 2x2 factorial design, there is no significant effect of functional similarity, but there is a significant effect of physical similarity ($F=4.157$; $df=1,75$; p less than .05). In other words, no matter how the simulator functions, in this task subjects perform better if the simulator is more physically similar to the actual equipment.

These results must be considered inconclusive and further analyses are required. Though the above analyses are only on terminal performance, additional analyses will compare the subject's rate of learning by examining performance over time. Also some form of blocking of subjects may be attempted to reduce within group variance. Even so, these data are an important first step in validating the 9 cell approach to fidelity research and show that this is a viable method for generating basic data on the relationship of simulator fideltiv to training effectiveness.

Generating Data on Interactive Variables

The above perceptual-motor experiment yielded valuable data on the relationship of the physical and functional aspects of fidelity to training effectiveness, but only for that specific task. Other tasks and other interactive variables require further investigation. ARI, through its basic research (6.1) program, is beginning to collect data on these interactive variables.

One 6.1 effort, currently underway at George Mason University, involves constructing both a generic device to use as an electro-mechanical/hydraulic reference system and several degraded simulations of that reference system. The idea here is that the reference system will serve in the role of actual equipment. It will function in a variety of ways such as turning on pumps, generating tones, turning on lights or fans, none of which really "do" anything. However malfunctions will be introduced into the system and trainees will have to troubleshoot and repair it.

Different groups will be trained on either the actual equipment (the reference device) or on one of several simulators of the reference system with varied degrees of fidelity. The performance of individuals from each group will then be measured on the reference device to determine the degree of training transfer for each level of fidelity and mixture of interactive variables.

This experimental paradigm will provide an opportunity to generate, under controlled laboratory conditions, the basic data needed on many of the interactive variables in the fidelity training effectiveness relationship (see Table 1). Data collection will begin in the Spring of 1983 after the reference device and simulators have been constructed. Systematic inclusion of interactive variables will begin after initial baseline data have been collected. The entire effort is expected to conclude in the Summer of 1985.

The Future: Building a Data Base

The goal of ARI's Training Simulation research program is to produce a user oriented guidance package to help determine the characteristics which should be incorporated into training simulators to insure both training and cost effectiveness. It is the strategy of this research program to base such a guidance package on empirical data.

Data Base Sources

Three major sources of data will be used to construct the training device characteristics data base. First, previously conducted studies will be evaluated to determine whether the data generated from these efforts are suitable for inclusion in the data base. If so, the data will be categorized and added to the data base. If not the particular study will be categorized so that additional efforts can fill in the gap in the data base. At present, this evaluation of previous research is under way and it is expected to be completed during the Fall of 1982. An ARI Technical Report (5) which accumulates and reviews the literature on training device research issues and which will serve as the organizing framework for the data base is in preparation. This paper is expected to be completed by January, 1983.

A second source of data for the data base will come from ARI's research efforts as described above. These efforts will not attempt to reinvent the wheel by duplicating previous studies which have been deemed adequate. They will rather focus on gaps in existing data, either because previous efforts have not addressed the right questions, because data are not valid and reliable, or because the results are not systematic enough for inclusion in the data base. The wheel truing experiment described above is the first entry from this data source. Other basic (6.1) and applied (6.2) research efforts are presently being conceived and statements of work (SOWs) are in preparation.

It is anticipated that enough data will be accumulated by 1984 that a preliminary iteration of the guidance package may be produced. This guidance package will probably start as a workbook but will eventually be automated for access via computer terminals.

Accessing the Data Base

In order to make the training device characteristics data base more than just an academic exercise, it is necessary to insure that the individuals who need guidance in specifying training device characteristics have access to the data base. At this time there are tentative plans to automate the data base in order to allow users direct access to the data. A preliminary step to automating the data base is to organize it arround user oriented research issues. This organizational effort is currently underway and a data base framework should be produced in the Fall of 1982.

Once a basic framework for the data base is developed it can be used as the basis for an automated delivery system. Such a system, using computer terminals, would afford access for decision makers at various points in the ISD process. It would also allow frequent updating as new and better data are developed. The iterative nature of the proposed data base can insure that the training community will have the most recent data available on a wide variety of training device research issues. With access to such data, the development of training devices need not rely on intuition but rather on the best available information on training effectiveness.

Conclusion

ARI is pursuing a broad research program aimed at building a data base which will relate training simulation design characteristics to transfer of training effectiveness. An initial framework for data collection built around a parsimonious definition of simulation fidelity has been constructed and is being used to guide a series of on-going and planned laboratory experiments. The long range objective is to create a comprehensive simulation design data base and to evolve that data base into a tool which can aid in specifying training device requirements.

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IMPLEMENTATION OF INSTRUCTIONAL FEATURES ON MAINTENANCE TRAINERS

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ABSTRACT

Automated instruction aids on a training device can significantly enhance the effectiveness of the device. However, the requirements for these aids (Instructional Features) must be consistent with the intended use of the trainer. If they are not consistent, the system implemented may be either more complex than required, or totally inadequate. This paper describes the development of Instructional Features where this inconsistency did exist. In this case the general processing requirements for student monitoring, student feedback, instructor reports and instructor controls were established. However, the specific in-classroom use of each was not. When the specific requirements were established, they were significantly less than the general processing requirements implied. The system design did meet both the general and specific requirements. However, a simpler approach would have satisfied the actually-used Instructional Features. This clearly shows the need to consider the specific classroom use of Instructional Features not just the general processing requirements.

INTRODUCTION

This paper presents the development of Instructional Features for a Simulated Aircraft Maintenance Trainer (SAMT). The initial concept, the software system design and implementation, an analysis of actual application versus the original intent and the factors to be considered in the application of Instructional Features to other trainer systems are discussed. The term Instructional Features for this paper is constrained to means the amount of automated monitoring of a student's progress through a task, feedback provided to the student, post lesson reports for the instructor, and instructor control of information presented to the student.

The trainer system for which the Instructional Features were developed is composed of ten different standalone trainers. The ten trainers correspond to the following aircraft subsystems: fire control, flight control instruments, navigation, electrical, environmental, hydraulics, weapon control, engine start, engine diagnostic and engine operating procedures. Each trainer consists of a master simulation control console (MSCC) and a simulation panel set (SPS). Figure 1 is the block diagram for a typical trainer. The MSCC contains the Honeywell Level 6 computer, a mass storage device, a lineprinter, a CRT and keyboard and a 35 MM projection system. The MSCC is identical for each trainer. The SPS is unique for each trainer and consists of one or two panels. On the SPS are the simulated aircraft controls and indicators and simulated test sets for the aircraft subsystem involved. Graphics on the panels provide for location of the control and indicator on the aircraft. In addition to the aircraft and test set controls and indicators, there are action and element switches on the panels. The action switches provide the capability for the student to indicate his knowledge that a certain action, such as hose/cable connection, operation of hand pumps, aircraft safing actions, etc., is required as he proceeds through a task. The element switches provide to the student the capability to indicate which component he has isolated as being faulty or to call up a 35 MM slide of a particular component.

INITIAL INSTRUCTIONAL FEATURES CONCEPT

The initial objectives for the Instructional Features were to support: (1) student testing, (2) lecturing, (3) fault isolation treeing, and (4) self-directed learning. To accomplish these objectives, the Instructional Features were to provide: (1) monitoring of a student's progress through a tree structured sequence, (2) student feedback, (3) student testing, (4) instructor reports, and (5) instructor control over these features.

- The student monitoring was to be at a level that the trainer could uniquely respond to and/or record a student's selection of each branch and/or step in a Job Guide (JG) or Fault Isolation Manual (FIM).

- Feedback to the student was to be a CRT message, 35 MM slide, an audible sound, or any combination of these. The feedback was provided to cue the student, warn the student, or suspend execution of the lesson as a result of student branch selection or action taken on the trainer. The cues providing instructions and checkout aids required to lead the student through the training exercise (a set of procedures from the JG and/or FIM). The warnings being for procedural and operational errors, systems malfunctions and safety violations.

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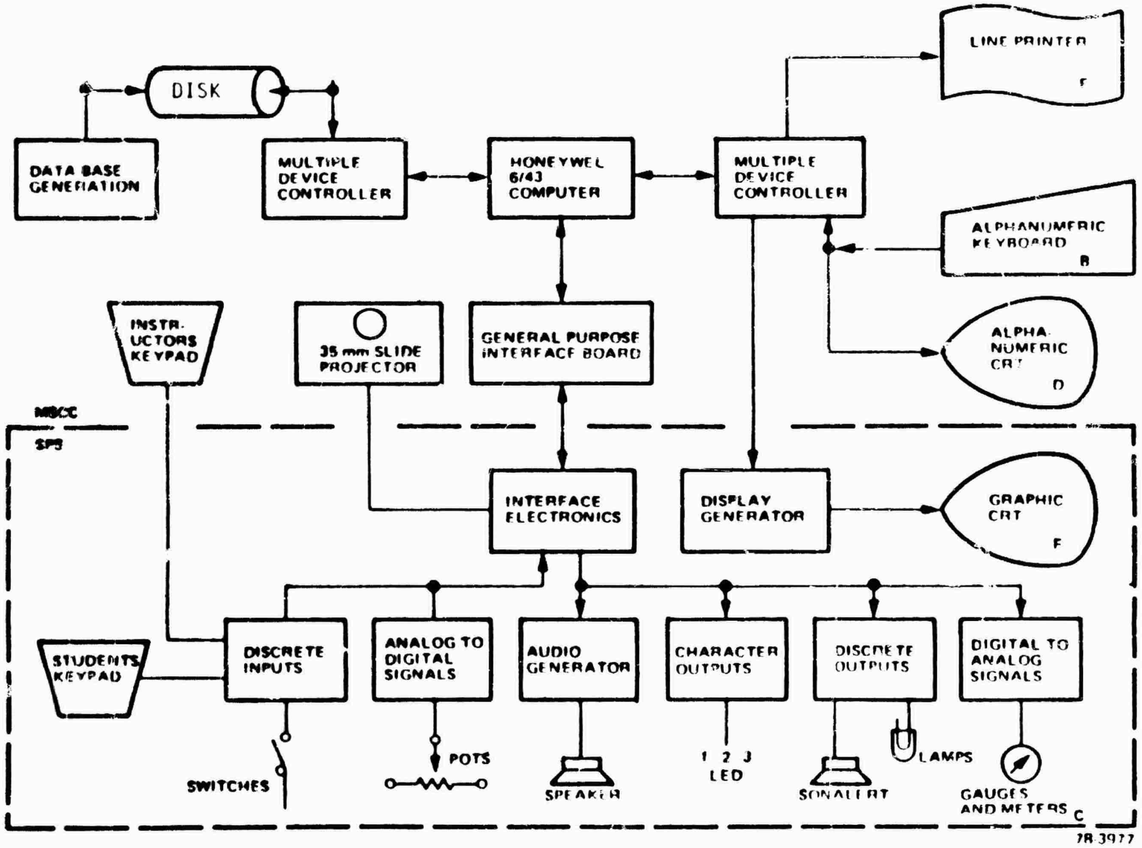

Figure 1. F-16 SAMT Interface Block Diagram

- Student testing was the presenting of questions with the follow-on sequence being determined by the student's response.

- The instructor reports were to consist of student responses to test questions, procedural and operational errors made, safety errors, actions taken on the trainer and branch selections made.

- Controls provided to the instructor were to consist of malfunction selection, entry and modification of plans of instructions, amount of feedback and modification of testing materials, self-directed learning materials (cues and warnings) and fault isolation schemes. Plans of instructions were the mix and ordering of student testing, lecturing, and fault isolation treeing. The amount of feedback to be controlled by levels of aiding selected by the instructor.

SOFTWARE SYSTEM DESIGN

The software system design and implementation to meet the Instructional Features requirements consisted of a Courseware Authoring Language Generator (CALGEN) and an on-line real time interpreter (Procedure Monitor). The actual monitoring, recording and feedback is specified in the CAL which is a high level source language. The source is input to the CALGEN, checked for errors and decoded into an object code. The interpreter decodes the CAL object code for each student action determining the correctness, providing the student feedback and recording the action.

The CAL was designed to provide a friendly interface to the training analyst developing the step-by-step training exercise for the student. This software (courseware) being based on the step-by-step actions called out in the aircraft technical orders and/or job guides.

The basic language constructs are:

<u>STRUCTURAL COMMANDS</u>

```
PROCEDURE <NAME>
GLOBAL VARIABLES ARE <LIST>
LOCAL VARIABLES ARE <LIST>
   MONITOR <NAME> WATCHING <ACTION LIST>
   END MONITOR <NAME>
END PROCEDURE
```

<u>ACTION EVALUATION/RESPONSE COMMANDS</u>

```
EXPECT <ACTION LIST>
ALLOWING <ACTION LIST>
UNLESS <ACTION LIST>

     / EQUIPMENT \       / STATE \
SET <    NAME     > TO <  VALUE  >
     \ VARIABLE  /
```

<u>ACTION EVALUATION/RESPONSE COMMANDS</u> (CONT.)

```
                  / HIGH \
PROJECT <N> FOR <   MED   > AIDING
                  \ LOW  /

DISPLAY <MESSAGE>

    / PRINTER \
AT <  DISC     >
    \ CRT     /

     / HIGH \
FOR <  MED   >  AIDING
     \ LOW  /
```

<u>CONTROL COMMANDS</u>

```
INVOKE <MONITOR NAME> AT PRIORITY <N>

FORCE <MONITOR NAME> TO <SUSPEND
                         RESUME>

TERMINATE <MONITOR NAME>
IF <CONDITION> THEN
GO TO <LABEL>
ESCAPE <N>
```

<u>WRITER'S CRAMP COMMANDS</u>

```
ABBREVIATE <STRING> MEANS <STRING>
INCLUDE <FILE NAME>

                                    LOGICAL \
MAP SLIDE <PHYSICAL NUMBER =        NUMBER   >
                                    LIST    /
```

These constructs can be used to provide student monitoring with error detection, aiding and equipment simulation. An example of this is:

```
L:  EXPECT SAFETY_LATCH

EXPECT SAFETY_LATCH = ON  ALLOWING NONE
UNLESS NONE

   IF CORRECT THEN GO TO L:SAFE_TO_PROCEED
   END IF

   (ELSE THE WRONG ACTION WAS TAKEN)

   DISPLAY "Place safety latch on" AT CRT
   FOR LOW AIDING

   GO TO L:EXPECT_SAFETY_LATCH

END EXPECT

L:  SAFE_TO_PROCEED

     SET READY_TO_PROCEED_LIGHT TO ON
```

```
L:  SAFE_TO_PROCEED (CONT.)

     PROJECT 23 FOR HIGH AIDING

                .

                .

                .
```

CAL can be used to provide student testing. An example of this is:

```
L:  DISPLAY_COOLING_AIR_QUESTION

    DISPLAY "Should cooling air be applied
            before the main electrical
            power supply is hooked up?" AT
            CRT

    EXPECT C_IRN = AN_KYBD_STRING ALLOWING

    ANY UNLESS NONE END EXPECT

    IF AN_KYBD_STRING = 'NO' THEN

       DISPLAY "Error in choice of cooling
               air application" AT DISK

       DISPLAY "T.O. JG-11-00 provides in-
               formation concerning the
               application of cooling air.
               Would it be proper to recon-
               sider your last answer?"  AT
               CRT

    EXPECT AN_KYBD_STRING = 'YES' GO
    TO L:DISPLAY_MENU END IF

    (A more specific aid is needed)

    DISPLAY "On page 59 of T.O. JG-11-00
    there is information concerning the
    application of cooling air" AT CRT

    GO TO L:DISPLAY_MENU

    END IF

L:FRONT_PANEL_QUESTION

    DISPLAY "Should the front panel be
            removed before the application
            of the main electrical power
            supply?"

                .

                .

                .
```

As can be seen from the language constructs and by these examples, the courseware can be constructed to provide monitoring of student performance by comparing actual actions against a predefined:

- Single action
- Set of actions which must be performed sequentially
- Set of actions which may be performed in any order
- Set of actions which are extraneous and to be ignored
- Number of actions
- Time

It provides presentation of:

- Simulated device responses
- Pictorial material
- CRT messages

CAL provides feedback for:

- Correct actions
- Incorrect actions
- Time
- Number of actions

Figure 2 describes the courseware generation process and the interface to the on-line trainer software. The first step in this process is the annotation of the T.O.s or Job Guides. Annotation is the specifying of the student monitoring, feedback responses, error processing and recording requirements for each step in the T.O.s. The CAL source is coded based on the annotated T.O.s. CALGEN is used to compile the source code. The object code generated is produced as a set of files on the disk used by the operational software. The object code is interpreted by the on-line, real time trainer software providing the desired student monitoring, feedback and report generation.

The on-line SAMT software system provides two major functions: a simulation model function and a trainer control function The simulation model simulates normal and malfunctioning aircraft system operation by supplying appropriate responses to simulation panel set (SPS) inputs. The trainer control function has overall control of the training function including initialization, training exercise preparation, training exercise presentation, monitoring of the student action and comparison of the action for compliance with the courseware.

In addition, input and output subfunctions are provided which condition and control the data flow to and from the computer. A Powerfail function provides for resumption of a problem exercise interrupted by a power failure. An operating system provides a multi-tasking environment, standard peripheral interfaces and file management. A Kernel component which provides interfaces between the other software components and the operating system. The Kernel dispatches execution according to priority, state of the training system and real time.

Figure 2

COURSEWARE PREPARATION FLOW

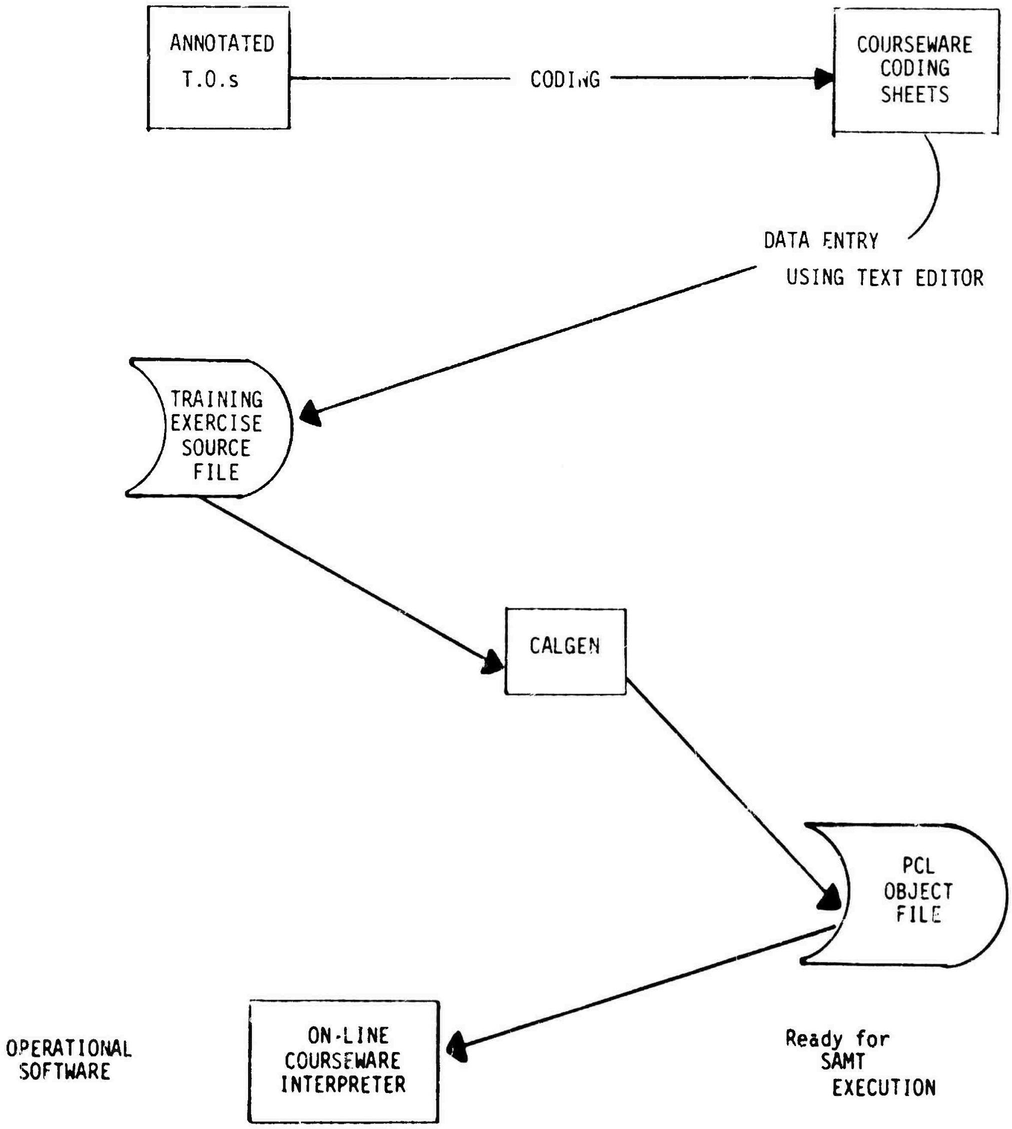

Figure 3 shows the operational software hierarchy. The Instructional Features requirements are satisfied within the trainer control function. The control courseware provides services generic to the SAMT. Training courseware provides T.O. unique information. The Procedure Monitor is the on-line interpreter of the courseware. The training courseware specifies what student inputs (from the panel or the keyboard) and in what order these actions are to occur. The training courseware can also specify what response is to be generated for a given action. The response may be a display on the SPS, a CRT message, 35 MM slide and/or problem freeze. Thus providing equipment simulation, student aiding, error feedback and/or student testing. Training courseware also specifies what information is to be recorded in the student record.

The control courseware controls the training courseware and provides the instructor control. These controls are:

1. problem exercise list
2. message modification
3. status report call up
4. freeze enable

The problem exercise consists of up to 15 elements which define an exercise to be performed by the student. These elements are:

1. procedure -- Job Guide or fault isolation procedure contained in the training courseware.

2. malfunction

3. aiding level -- The student aiding level may be low, medium or high.

4. parameter -- simulation variables such as temperature, oil pressure and fuel quantity.

5. Sign IN -- Instruction to the student to enter his name and identification. This information is then entered in the training record.

6. time limit -- Alloted time for the student to complete the exercise. If the student exceeds this time, a message is displayed and the exercise halted.

7. action limit -- number of action steps to be taken by the student in performing the exercise. If this number is exceeded, a message is displayed and the exercise halted.

8. lesson -- precanned problem exercises stored on the disk.

These elements are entered by the instructor in the order he desires. The list is then processed sequentially. This allows the instructor to select a combination of malfunctions and procedures to be performed and to specify under what conditions (aiding level, parameters, time and number of actions). The lesson element provides for routinely performed training sessions without the instructor having to reenter all elements each time. A typical problem exercise might be:

1. Sign IN
2. aiding level high
3. temperature parameter 73^{o}
4. action count 75
5. malfunction 1
6. procedure XXX
7. procedure YYY
8. malfunction 3
9. procedure AAA
10. procedure BBB

Items 6 and 9 being the operational check procedure which would detect the malfunction and items 7 and 10 being the fault isolation procedures for the specific malfunction.

The message modification control allows the instructor to temporarily modify messages contained in the training courseware.

The status control allows the instructor to request display of the training record. The training record consists of the date and the sequentially logged data consisting of P.E. list item, state of system freeze, malfunction, aiding level, actual time, action counts, student name, and identification and items directed to be recorded by the training courseware.

Freeze control allows the instructor to enable/disable halting of the exercise automatically when the student commits a hazardous error.

SPECIFIC REQUIREMENTS VS. CONCEPT

The software system was designed based on the initial Instructional Features requirements. When the detailed Instructional Features objectives (specific use of the trainer) were available, it was obvious that they were significantly less than the original concept. The specific objectives of the student monitoring requirements consisted of:

1. critical/hazardous actions -- Monitor the warnings and cautions in the Job Guides.

2. completion criteria -- Monitor that a few specific actions were accomplished by the student before allowing him to complete a procedure. The specific actions may be procedure unique.

3. malfunction removal prerequisites -- these prerequisites are not procedure dependent but are airplane subsystem dependent. It consists of monitoring for certain actions being accomplished before the student is allowed to identify which component he believes has failed.

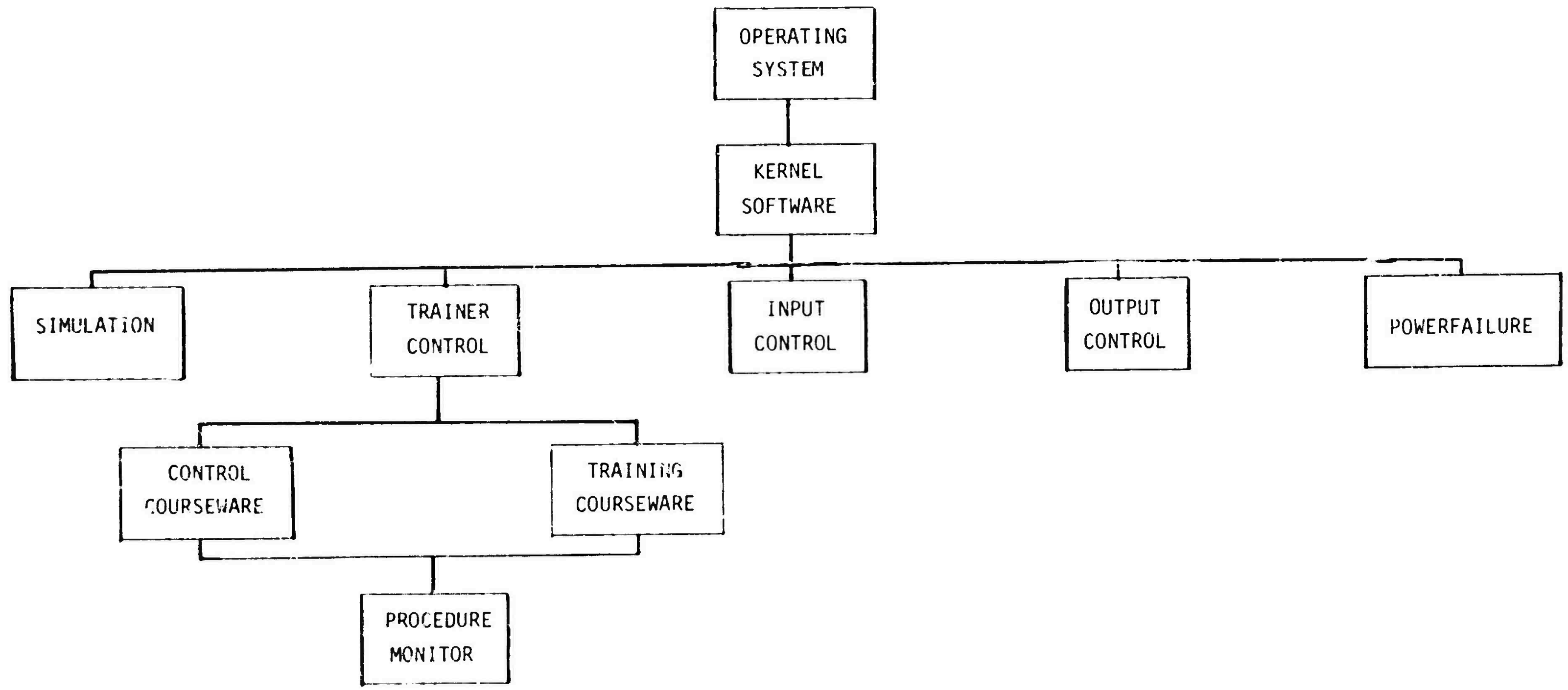

Figure 3. Software Hierarchy

4. time monitor -- Monitor the length of time the student required to complete a procedure

5. action monitor -- Monitor the number of actions the student made in completing a procedure.

The reasons for the significant difference between the initial concept of the Instructional Features and the final concept fall into three areas:

1. The general requirements for the training had been determined, but the specific in-classroom use of the trainer had not been established. The specific uses were not determined until the subject matter expert (SME) was asked to define the intended use of each Instructional Feature. This was done to allow the specific training courseware for each procedure to be specified and generated.

2. The full capability of the Instructional Features was not required by the SMEs for two reasons:

a) The instructors are present during the training exercise and can provide the aiding necessary.

b) The Job Guides have a high rate of change for a new weapon system, therefore making it difficult to keep step-by-step courseware monitoring current with the Job Guide.

3. The cueing or student aiding requirement was more state dependent than Job Guide step dependent than was originally thought. That is, a cue is required at the completion of a task or subtask at each step.

APPLICATION OF INSTRUCTIONAL FEATURES

In some cases, the development of a system to meet a larger spectrum of Instructional Features may be desirable. In other cases this may not be true. There are several factors which must be considered in making that decision. Some of these factors are:

1. Is the system for which the maintenance trainer is being developed mature? In this case, the T.O.s are available and have a low rate of change.

2. Is the training to be performed for theory of general system operation? In this case, representative T.O.s or procedures can be used and the changes of the actual equipment T.O.s need to be incorporated only when they represent changes in the theory of operation.

3. Is the training objective, familiarization with the T.O. system? Again, representative T.O.s can be used.

4. What is the level of training to be provided? Entry level or basic training requires more aides and cues to assist the student initially and then gradually remove the crutches.

5. Is it desired to have uniformity of training, that is, less dependent on individual instructors? The trainer providing at least the minimum aiding and evaluation ensures all students receive minimum level of instruction.

6. Is there a high student to instructor ratio? In this case, both the student and the instructor need help (automatic student aiding and monitoring and student performance reports).

7. Is the requirement conversion training, that is, training a B-52 maintenance man to maintain B-1's? In this case, he is familiar with the T.O. system. He will group tasks rather than performing them in series. The student does this because he is able to look ahead. For example, he knows that he can make all connections to a given piece of equipment at once and save time rather than when they are called out in the T.O. In this case, procedural aiding does not apply.

8. Is it desired to have consistent training at more than one level? In this case, where training is to be provided for entry as well as "conversion training," the Instructional Features need to be and can be diminishable and tailorable to meet all levels.

SUMMARY

The system developed to meet the initial concept of Instructional Features does meet those requirements as well as the specific final requirements. This fact shows that the Instructional Features for a trainer system can be designed to meet several applications. However, it is obvious that a less sophisticated system would have met the final requirements. As can be seen from this example, Instructional Features must be determined in two phases: 1) determine the general features required by evaluating the intended use of the trainer, and 2) evaluate the specific classroom use of each feature.

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AUTOMATED PERFORMANCE MEASUREMENT: AN OVERVIEW AND ASSESSMENT

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ABSTRACT

This paper presents a case for greater utilization of automated performance measurement (APM) in flight simulators. The paper mentions the beginnings of APM, and describes in some detail the current variations, such as checkrides, automissions, parameter recording, procedure monitoring, and others. It discusses the attitude toward APM of different users, with particular reference to each of the identified variations. Finally, it presents conclusions designed to improve users' understanding of APM and increase appreciation of how it can assist instructors.

INTRODUCTION

Performance measurement is one of the more challenging areas of flight simulation. The ability to place students in demanding situations and to safely and accurately evaluate how they perform is among a simulator's greatest assets. It should be exploited.

In an operational flight trainer (OFT) or a weapon system trainer (WST) the instructor observes the student's performance during a training exercise from either an on-board or a remote instructor station. With an on-board instructor station the instructor is usually seated directly behind the pilot or copilot (most on-board instructor stations are used in simulators for multi-place aircraft) and can directly view the student's actions and the resulting indications on the instruments or on the visual system display. While this arrangement has many advantages, particularly in enabling the instructor to detect hesitation or confusion in the cockpit, it leads to subjective evaluations, which in turn are conducive to variability and inaccuracy. Also, because all of the instruments and switches in the cockpit are not always clearly visible to the instructor, he may not be able to obtain all of the data needed for precise evaluation.

With a remote instructor station, the instructor is seated at a console that can contain several CRT's and a visual system monitor, supplemented in some cases by repeater instruments. He observes the student's performance primarily by referring to a number of CRT displays that depict the simulated aircraft's flight graphically and numerically. Many of the on-board instructor station's limitations in obtaining data are removed, but the instructor may not be able to assimilate and utilize the full amount of information that is being presented or is available. Furthermore, the problems of insuring objectivity and uniformity will remain if the evaluation of the quality of the student's performance is made solely by human judgment.

In recent years automated performance measurement (APM) has been used to varying degrees to correct these problems. The digital computer used in modern flight simulators has a tremendous capacity for high speed, high volume data processing and is able to make timely and accurate comparisons of student-achieved flight parameters with predetermined standards. Imaginative designers and creative programmers have produced computer programs and CRT displays that present the results to instructors and students in a variety of ways. There is evidence, however, that the potential of APM has not been uniformly appreciated among the users of flight simulators, and its capabilities are often unexploited.

The purpose of this paper is to survey the "state-of-the-art" of APM, from the viewpoint of a contractor who builds flight simulators in response to Government specifications. Specifically, the paper will identify the various uses of APM found in current simulators, will discuss the related programs, or instructional capabilities, and will examine the different types of displays that are associated with these programs. In addition, the paper will discuss the opinions of users regarding these versions of APM, and will present conclusions and recommendations for consideration by persons who are responsible for the contents of specifications.

VARIATIONS

Automated performance measurement is defined, for the purpose of this paper, as the process of evaluating student performance primarily through use of the computer, and expressing the results in a numerical format. There are many instances in the conduct of training in a flight simulator where computer-derived data is used to facilitate a human-derived evaluation being made, but these are not considered to be within the definition of APM. The hallmark of APM is whether the computer produces a score, or a number of scores, that purport to express the performance of the student.

Based on the above definition, the origin of APM can be no farther in the past than the first use of digital computers in flight simulators, which occurred in the early 1960's.(1) It has been reported that Device 2F90, the TA-4J Operational Flight Trainer, was the first trainer to use "computer automated scoring".(2) The first unit of this trainer, which was built by Goodyear, was delivered to the Navy in 1969. A slightly more recent trainer, Device 2B24, the UH-1H Helicopter Instrument Flight Trainer, employed an adaptive training mode in which the computer evaluated student performance on certain tasks and advanced him to higher difficulty levels based on his proficiency.(3) This trainer, built by Link, was also known as the Synthetic Flight Training System.

Currently, the uses of APM have proliferated to the extent that a number of variations can be found in every simulator. They range from complex, highly automated programs to simple graphic presentations, some of which, in fact, do not fully fit the definition of APM. The following is a description of each type of APM program, insofar as specific, unique types can be identified, and a discussion of its usefulness to an instructor.

Checkrides

Checkrides can be considered to be the classical form of APM. A checkride is a mission or profile in which the computer monitors the student performance, usually from takeoff to final landing, without intervention by the instructor. The common use of checkride is the evaluation of proficiency in instrument flight.

Sometimes the term "programmed mission" is used to describe a check-ride. In the EA-6B WST specification, for example, programmed mission is used, but the contractor chose to use the term "computer-evaluated mission" instead, considering it to be more descriptive. The specification for the F/A-18 OFT calls for "programmed missions in either the checkride or automission mode" (see below for a discussion of automissions).

An essential characteristic of checkrides is the prevention of the instructor from making on-line modifications to the mission, through varying the environmental conditions, introducing malfunctions, or tightening or relaxing the evaluation criteria.

Ideally, checkrides should be designed so that the instructor is not required to be involved during the mission other than to start the computer program. To this end, checkrides usually consist of a series of segments or legs with the end conditions of each leg defined so that the computer automatically advances to the next leg at the proper time. During each leg the computer monitors a number of parameters, or variables, (heading, altitude and airspeed, for example) and determines whether the student is within the criteria for satisfactory performance. While the terminology for the components of a checkride is not at all standardized, the value of a parameter that a student is attempting to maintain is commonly called the reference value (also the base value), the criteria for satisfactory accomplishment of each parameter in a leg are stated as tolerances, and instances of performance that are outside the prescribed tolerance are called errors or deviations.

Two types of CRT displays are usually provided for the instructor, to enable him to monitor the progress of the mission. One is a map display depicting the intended route of the aircraft and the actual track. Usually the legs of the checkride are indicated, and a symbol is sometimes displayed beside the appropriate leg when the tolerance has been exceeded.

Figure 1 illustrates one of the map displays for a checkride for the CH-53D OFT. The exercise is an instrument flight from MCAS Cherry Point to MCAS New River, North Carolina. In the lower right corner of the display is a table reporting the amount that any tolerance is being exceeded at that instant.

The other type of display commonly provided is an alphanumeric description of the leg currently being monitored plus at least the next leg. The specification for the A-6E OFT calls for three legs to be displayed. The display provided by the contractor, Sperry, monitors the preceding leg, the current leg, and the next leg. In the EA-6B WST, also built by Sperry, four legs are monitored: the preceding, the current, and the next two (the specification did not state how many were desired).

The display, which has been called by various titles such as the Scenario Display, Leg Data Display, or Alphanumeric Display, usually contains the number of each leg listed, a brief description of the maneuver being accomplished by the leg, the reference values for the monitored parameters, the related tolerances, and the end conditions for the leg. Sometimes a Remarks column is provided containing, among other information, current deviations. Figure 2 illustrates the Scenario Display for the EA-6B WST.

Designing a checkride so that the computer will infallibly recognize the end conditions of each leg is an art. Scenario designers must guard against a number of pitfalls: premature advancing of the computer program, failure to advance when the pilot commences a new leg, and the charging of invalid errors(4). In the final analysis, there probably will never be a fool-proof checkride, so perfectly designed that the computer will be able to cope with any gross error that a student can commit.

When the computer scoring becomes disassociated with the flight profile of the simulator, whatever the reason, the instructor must either abort the mission or take action to realign the scoring. Many simulators that have a checkride feature are equipped with a switch, sometimes labeled Manual Advance, to enable the instructor to advance the computer scoring to the next leg. In fact, the specification for the A-6E OFT requires a "control to start the next leg of the mission prior to expiration of indicated time", presumably referring to a manual advance. Some trainers have an additional switch to retract the computer scoring to the previous leg. Of course, there should be a way for the instructor to "forgive" any leg with invalid errors.

The results of the mission can be presented to the instructor in many ways. Typically a summary display is provided that lists for each parameter, as a minimum, the total number of deviations recorded, the maximum deviation, and the cumulative time out of tolerance. The CEM

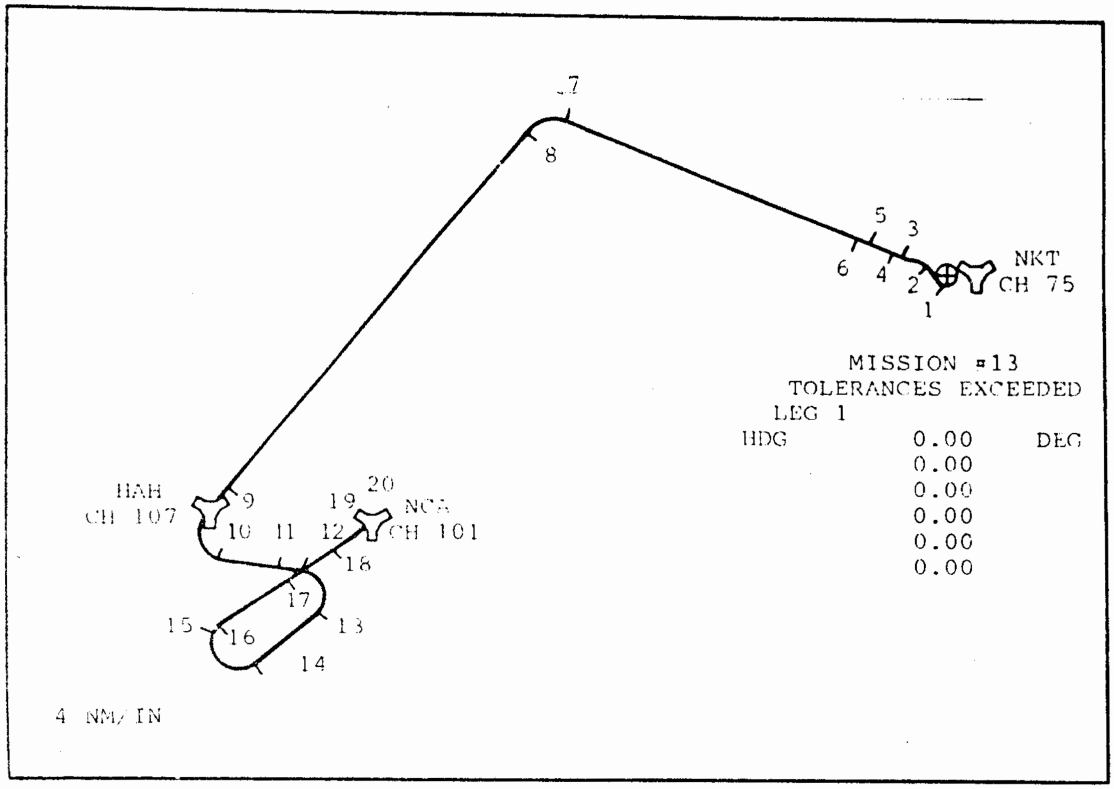

Figure 1. Checkride Map Display for CH-53D OFT

CEM SCENARIO DISPLAY

LEG NUMBER	DESCRIPTION	PARAMETERS MONITORED	LEG END CONDITIONS
2	DECELERATE TO 250 KT 3 MINUTES BEFORE TIMBER.	ALT 20000 +- 299 FT IAS 290 +- 50 KTS GT +- 2 NM.	DIST IAF + 12.5 NM.
*3	SPEED NOW STABLE AT 250 KTS.	ALT 20000 +- 200 FT IAS 250 +- 10 KTS GT +- 2 NM.	RAD =- 278 GPO OR DME =- 35 NM.
4	TURN LEFT. PROCEED INBOUND ON RAD 278 GPO. DESCEND TO 8500 FT.	ALT 14350 +- 5850 FT IAS 250 +- 10 KTS	DME =- 32 GPO
5	ESTABLISHED ON RADIAL. CONTINUE DESCENT TO 8500 FT.	ALT 14350 +- 5850 FT IAS 250 +- 10 KTS RAD 278 GPO +- 3 DEG	DME +- 20 GPO

Figure 2. CEM Scenario Display for EA-6B WST

Summary Display for the EA-6B WST (shown in Figure 3) also includes the total time recorded and the percentage of the total time recorded that was out of tolerance. This percentage can serve as a score.

Most persons trained in statistical analysis prefer other, more sophisticated methods of evaluating performance. The specification for the F/A-18 OFT, for example, calls for measurement by "RMS deviation technique" and mentions "Z scores". The RMS (root mean square) method produces a value which is the square root of the sum of each deviation squared, thus it penalizes the student (quite properly) for occasional wide deviations. In this method the deviation is measured from the arithmetic mean, assumed to be equal to the reference value, rather than from a tolerance. Z scores compare a student's performance with all others, using a statistical measure called the standard deviation. With Z scores the user is required to maintain a bank of data from all previous similar missions.

When these techniques were explained to the F/A-18 OFT Fleet Project Team and other user representatives at a design review meeting, the reaction was decidedly negative. Apparently the users considered that statistical approaches were not suited to training needs. Consequently, the checkride in the F/A-18 OFT uses the conventional, tolerance-oriented method of evaluation.

The CH-53 D/E OFT also used tolerances in its checkrides, but it has a Quality Control Display and program that enable the instructor to compare any checkride results with the "norm" of others in the data bank. The instructor can compare his student with all others, or with groups of pilots with generally the same total hours, instrument hours, or hours in the CH-53 aircraft. The comparisons are based on the percentage of time out of tolerance and the maximum deviation, for each parameter per leg.

Automissions

As used in some specifications, the term "automission" refers to a programmed mission in which the instructor is allowed to make on-line modifications. The term "automated training exercise" has also been used to identify the same capability. Neither term is adequately discriminating.

In some versions of automissions the instructor is permitted only to change the environmental conditions and introduce malfunctions. In others he can also change the scoring criteria, i.e. reduce or increase tolerances so to make the parameters more difficult or less difficult to maintain.

Automissions should use the same general displays as checkrides, i.e. a graphic display and a scenario display. Scoring should be based on tolerances rather than comparison with other students, since the latter method loses validity when the instructor modifies the mission.

Monitored Maneuvers

A unique approach for APM is being developed for the HU-25A and HH-65A Flight Training Systems, being built for the U.S. Coast Guard by Sperry. Rather than having an hour-long, or more, checkride containing a fixed flight path, the instructor will have available a number of separate programmed "maneuvers" which he will be able to monitor via the computer whenever they occur during a normal training exercise. These maneuvers will have legs, parameters, and end conditions like a checkride; however, they will each be only a few minutes in duration. They may include an instrument takeoff, a holding pattern, a number of published approaches, a GCA, and some malfunctions at critical times of flight. At any time during a training exercise, if the student is going to perform one of the monitorable

CEM SUMMARY
MISSION NUMBER 8

D 16

PARAMETERS MEASURED	NUMBER DEVIATIONS	MAX +DEV	MAX -DEV	CUM. TIME OUT	TOTAL TIME RECORDED	%
ALT	0	0.0 FT	0.0 FT	00:00:00	00:00:23	0.0
GEAR	0	0.0	0.0	00:00:00	00:00:00	0.0
FLAP	0	0.0 DEG	0.0 DEG	00:00:00	00:00:00	0.0
RAD	0	0.0 RADS	0.0 RADS	00:00:00	00:00:00	0.0
AOA	0	0.0 UNIT	0.0 UNIT	00:00:00	00:00:00	0.0
GT	0	0.0 NM	0.0 NM	00:00:00	00:00:23	0.0
IAS	1	0.0 KTS	7.9 KTS	00:00:04	00:00:23	17.4
ROC	0	0.0 FPM	0.0 FPM	00:00:00	00:00:00	0.0

Figure 3. CEM (Checkride) Summary Display for EA-6B WST

maneuvers, the instructor will be able to initiate the APM program and obtain a computer-derived evaluation of the student's performance of the maneuver.

The user's objective in specifying this approach was to provide the instructor more flexibility then he would have with a checkride. The user was concerned that students will become familiar with the sequence of maneuvers in a checkride thus reducing its validity as a measure of overall proficiency. With the monitored-maneuver approach the instructor can operate or withhold the monitoring program as he desires, thus the student does not know when he is being monitored. The student may learn what maneuvers are monitorable and therefore know when he is vulnerable, but he can never be sure if the program is operating.

It is interesting that the concept for the monitored-maneuver approach was first presented at the mock-up conference, early in the development of the simulators. It does not appear in the published specification.

Semi-Automated Performance Measurement

Some specifications suggest that the instructor at any time in a training exercise should be able to enter parameters and tolerances for computer monitoring. Since the instructor will have to control when the monitoring starts and stops, this capability could be called "semi-automated performance measuring".

A program to provide this capability was developed in 1976 for the A-4H and N OFT's, by the Simulation Engineering Corporation (now Sperry). A CRT page (see Figure 4) enabled the instructor to enter any desired reference value and allowed deviation, or tolerance, for up to 15 specified parameters. When entered, these values appeared under REF VAL and DEV in the STANDBY column on the page. When the instructor started the computer monitoring, by entering a value for START TIME or by designating START NOW, the parameter values would appear in the RECORDING COLUMN. The instructor could then enter new values in the STANDBY column in preparation for the next leg. A teletypewriter automatically printed out every entry made and the time out of tolerance plus the maximum deviation for each parameter monitored. If desired by the instructor, a summary was also printed reporting the total time out of tolerance and the total time measured for each parameter.

This program provided the ultimate in flexibility. However, the demands on the instructor were so great, if he attempted to monitor a number of legs sequentially, that he could handle only one or, at the most, two parameters per leg. By preplanning all entries and having an assistant operate the keyboard, an instructor could handle possibly three or four parameters simultaneously. His role was to determine precisely when to have the operator make the entries to start and stop monitoring each parameter, a decision that was critical to the validity of the scoring.

Parameter Recording

A number of specifications call for automated performance measuring "on a continuous basis as a function of time", and use the term "parameter recording" for this capability. The interpretation is usually made by contractors that a strip chart recording is desired, although specifications are customarily not that specific. When both checkrides and parameter recording are required on the same simulator, as is the case for the EA-6B WST, for example, the contractor is able to conclude, at least, that two different capabilities are desired.

The parameter recording program in the EA-6B WST can monitor up to 18 parameters simultaneous-

PERFORMANCE MEASURING P11

		RECORDING		STANDBY				RECORDING		STANDBY	
		REF VAL	DEV	REF VAL	DEV			REF VAL	DEV	REF VAL	DEV
01	IMN	X.XX	.XX	X.XX	.XX	11	ADF TRK	XXX	XX	XXX	XX
02	IAS	XXX	XXX	XXX	XXX	12	PIT RATE	XXX	XX	XXX	XX
03	T HDG	XXX	XXX	XXX	XXX	13	ROL RATE	XXX	XX	XXX	XX
04	AOA	XX	XX	XX	XX	14	YAW RATE	XXX	XX	XXX	XX
05	VVEL	±XXXX	±XXXX	±XXXX	±XXXX	15	RPM	XX	XX	XX	XX
06	ALT	XXXXX	XXXX	XXXXX	XXXXX	16	START TIME				XXX:XX
07	ACCEL	X.X	X.X	X.X	X.X	17	STOP TIME				XXX:XX
08	PITCH	XX	XX	XX	XX	18	START NOW				0
09	BANK	XX	XX	XX	XX	19	STOP NOW				0
10	TRN RT	X.X	X.X	X.X	X.X	20	SUMMARY				0

Figure 4. Page for Semi-Automated Performance Measuring (A-4H and N)

ly. The instructor can enter reference values and tolerances using a CRT page (see Figure 5) somewhat similar to the page for semi-automatic performance measuring for the A-4H and N. Since the EA-6B WST uses non-page dependent formats for data entry, an input code is required for each parameter, and initial, or default, values are provided for the reference values and tolerances. The instructor can modify these values as he desires during the exercise.

The results are continuously printed out on a Versatec printer-plotter. Each column of the printout has a center-line that represents the reference value and two boundary lines that depict the tolerance (see Figure 6). Some parameters, such as landing gear and flaps, merely indicate an up or down state.

The specification did not require a summary or analysis of the printout, so if the program were extensively used during a mission, the instructor would be faced with considerable raw data requiring interpretation. Another limitation is the fact that the printer-plotter cannot be used for other purposes, such as printing CRT displays, when the parameter recording program is operating. This problem can be corrected by adding another printer-plotter to the system--a solution that would increase the cost of the trainer.

Most specifications are not as ambitious as the one for the EA-6B WST. The parameter recording program for the A-6E OFT, for example, monitors only up to six parameters simultaneously, although the instructor can select them from a total of 19 available. The specification for the AV-8B Weapons Tactics Trainer calls for recording, displaying and printing values and tolerances for up to ten parameters, of 22 available. The latter specification stipulates a minimum printout rate of one copy per five seconds, which implies that a strip recording is not necessarily desired.

In the F/A-18 OFT the parameter recording program operates only in conjunction with programmed missions. Ten parameters can be monitored, and the results, in continuous trace form, are displayed in sets of two parameters each. There is no provision for specifying tolerances since the programmed missions contain the tolerances. Thus the parameter recording

PARAMETER RECORDING D 9

PARAMETER	CODE	REF VAL(F)	TOLERANCE(L)	STANDBY	RECORDING
HEADING (DEG)	HD	360.0	10.0	0	0
ALTITUDE (FT)	AL	15000.0	100.0	0	0
AIRSPEED (KIAS)	AS	320.0	20.0	0	0
ANGLE OF ATTACK (UNITS)	AA	17.0	3.0	0	0
ANGLE OF BANK (DEG)	AB	0.0	15.0	0	0
ACCELERATION (G)	AC	1.0	2.0	0	0
FLAPS (DEG)	FL	0.0	30.0	0	0
LANDING GEAR (1=DOWN)	LG	1	0	0	0
SPEEDBRAKE (1=OUT)	SB	1	0	0	0
RATE OF CLIMB	RC	0.0	500.0	0	0
RATE OF DESCENT	RD	0.0	500.0	0	0
RATE OF TURN (DEG/SEC)	RT	0.0	1.0	0	0
PITCH RATE (DEG/SEC)	PR	0.0	15.0	0	0
ROLL RATE (DEG/SEC)	RO	0.0	15.0	0	0
YAW RATE (DEG/SEC)	YR	0.0	15.0	0	0
GCA/CCA ELEVATION (FT)	GE	0.0	50.0	0	0
GCA/CCA AZIMUTH (DEG)	GA	0.0	100.0	0	0
GCA/CCA CENTERLINE (FT)	GC	0.0	100.0	0	0
RPM, LEFT (%)	RL	82.0	5.0	0	0
RPM, RIGHT (%)	RR	82.0	5.0	0	0
PITCH ANGLE (DEG)	PA	0.0	15.0	0	0
MACH (IMN)	MN	0.68	0.05	0	0
TACAN BEARING (DEG)	TB	360.0	2.0	0	0
DME (NM)	TD	20.0	2.0	0	0
ACLS ELEVATION (FT)	AE	0.0	20.0	0	0
ACLS AZIMUTH (DEG)	AZ	0.0	2.0	0	0
ACLS CENTERLINE (FT)	AR	0.0	50.0	0	0

ENABLE RECORDING	0
DISABLE RECORDING	
CLEAR HEADINGS	

Figure 5. Parameter Recording Display (Partial) for EA-6B WST

program is merely a graphical history of the flight.

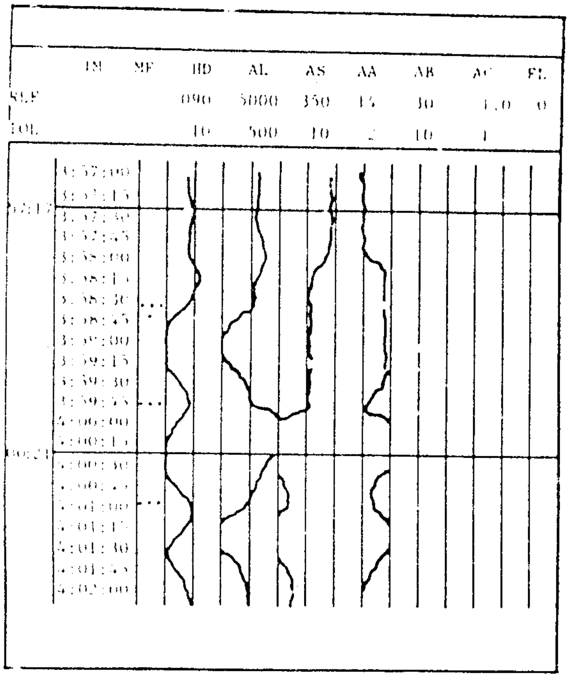

Figure 6. Parameter Recording Printout (Partial) for EA-6B WST

Weapon Scoring

The simplest use of APM is in scoring a weapon delivery. The computer evaluates the impact point based on simulation-derived data, a process that an instructor cannot possibly emulate, and displays the results graphically or numerically, or both. The final score is very easy to interpret: the student dropped his bomb acceptably close to the target or not.

Most displays of weapon deliveries feature a target with concentric circles depicting range errors. The A-6E Team Tactics Trainer, being built by Sperry, will combine a target display with delivery data that will include the miss distance, clock code (indicating the azimuth error), the cumulative CEP for the mission, and the probability of kill based on the weapon type and target characteristics (see Figure 7).

An additional display will show the read-outs from the Digital Display Unit (DDU) in the cockpit. These readouts, which are available to the bombardier/navigator after each bomb run, include parametric data such as the airspeed and altitude at bomb release, the wind direction and velocity, pitch and g's for the aircraft, as well as others. From the DDU data the instructor can reconstruct the release conditions and analyze the impact errors.

The specification does not call for a

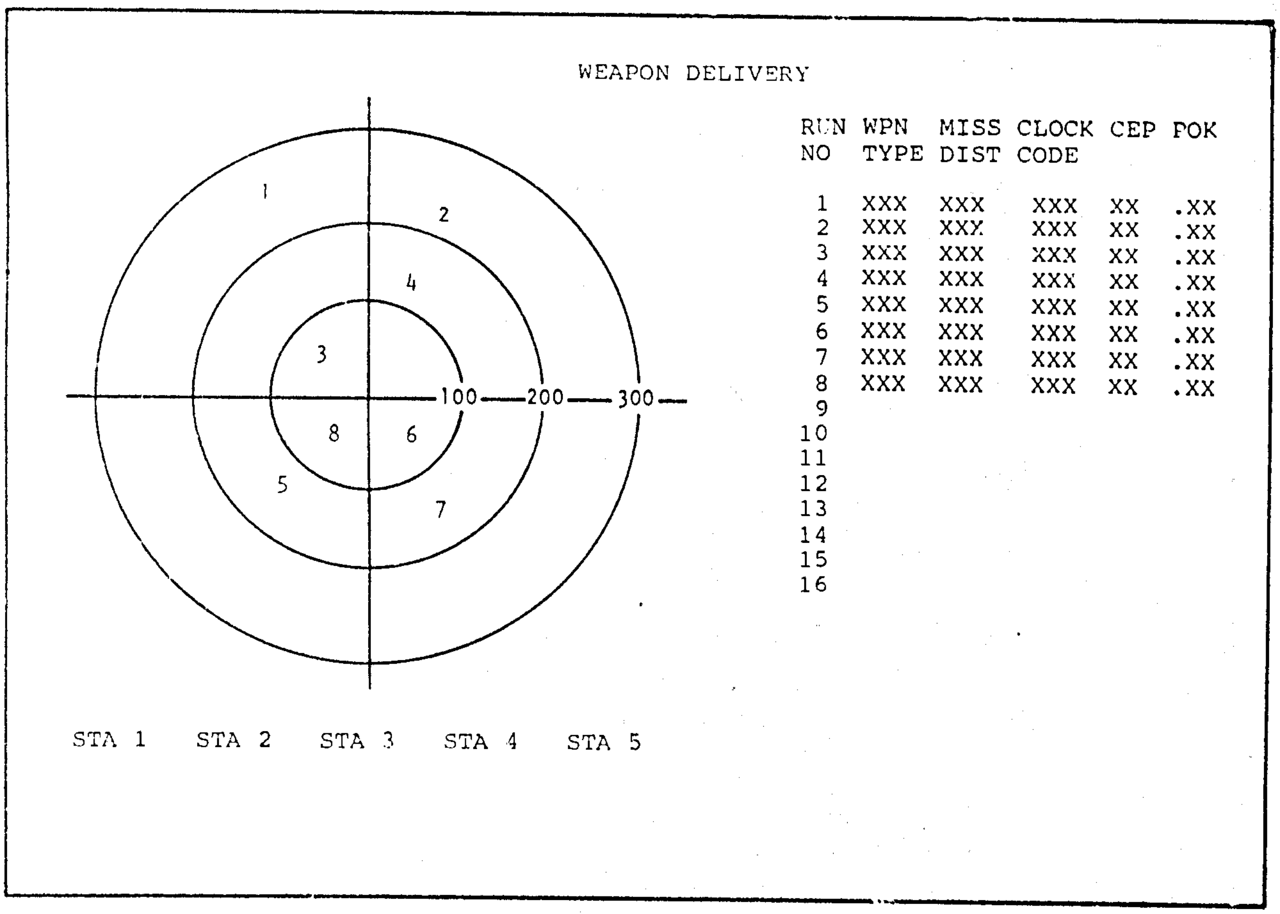

Figure 7. Weapon Delivery Display (A-6E Team Tactics Trainer)

computer-derived analysis of the bomb runs (only the impact point is calculated), although it would seem that this would be an excellent use of APM.

Air-to-Air Combat

The role of APM in air-to-air combat simulation is basically similar to that in weapon scoring. The computer analyzes the geometry of the intercept, checks the student's switchology, assesses the position of the steering dot at the moment of firing, and makes an assumption about the P_k (probability of kill) of the weapon used, and from these calculations determines whether a kill was achieved or not. An instructor would be able to make the same evaluation subjectively, but more slowly, of course, and always with the possibility of error.

The displays for air-to-air combat can range from highly sophisticated, depicting dynamically the three-dimensional relative position of the two maneuvering aircraft, to relatively simple, consisting merely of a map display showing "ownship" and the hostiles. In any case, the display will show the results of the engagement in the form of a kill or no-kill statement, usually accompanied by some type of analysis.

Procedure Monitoring

Procedure monitoring is a program that enables the instructor to evaluate how well a student accomplishes the required steps in a published procedure, such as the interior inspection checklist (a "normal" procedure) or the engine failure emergency procedure. When procedure monitoring is specified, the contractor is usually required to develop a very extensive library of CRT displays, normally one page per procedure. In some specifications two procedures per page are stipulated.

A procedure display typically lists the steps in the required sequential order, and indicates the order of actual accomplishment, either by an additional column of numbers or by listing the numbers across the bottom (see Figure 8). In some simulators the instructor is able to control when the procedure is "active" and subject to monitoring, and their displays show the elapsed time for completing the procedure.

There are no known specifications that call for an overall evaluation or score of a student's accomplishment of the normal and emergency procedures that he is faced with during an exercise. This would be within the capabilities of APM, but the algorithms would have to cope with the fact that in many procedures there are steps, such as those that state "visually check" or "as required", that cannot be evaluated by the computer. Currently the displays simply ignore whether these steps

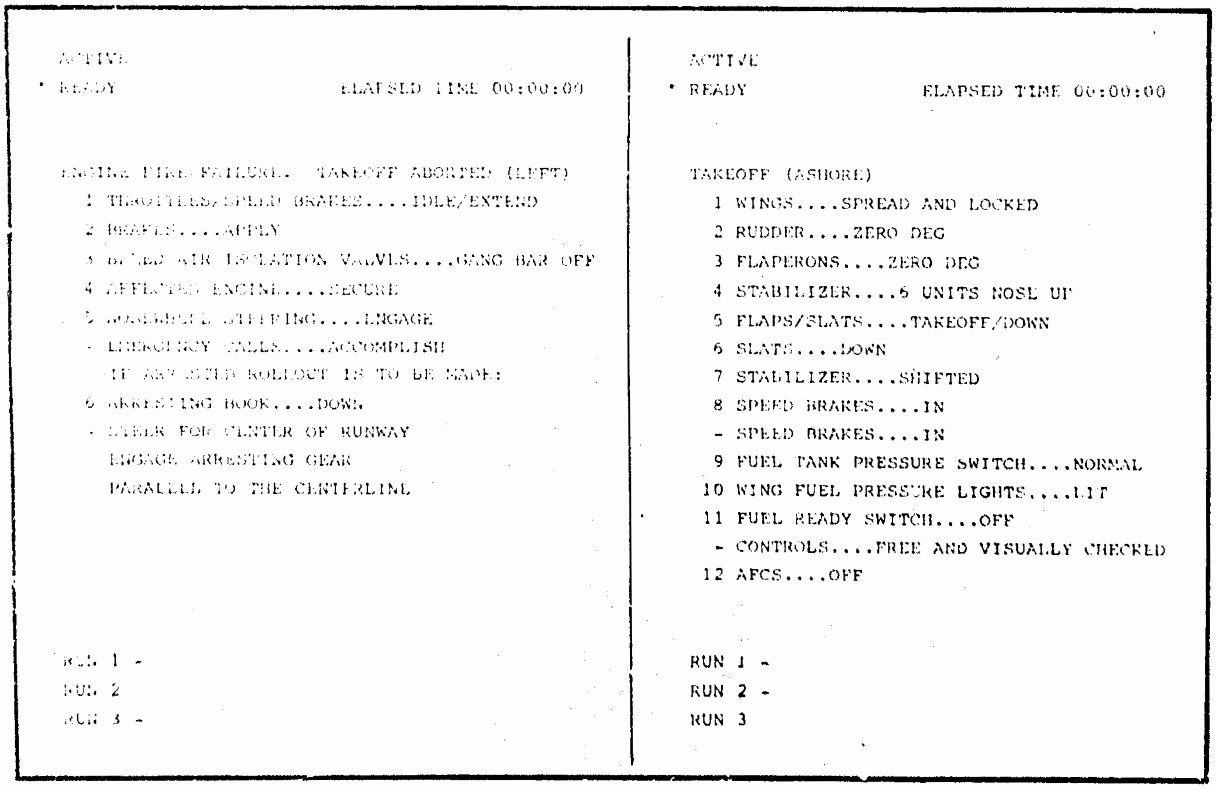

Figure 8. Procedure Monitoring Display for A-6E OFT

are accomplished or not, or assume that they are. The instructor is expected to make the necessary allowances in his mental evaluation.

Usually, simulators that have on-board instructor stations do not have the procedure-monitoring feature, presumably on the premise that the instructor can adequately determine by over-the-shoulder observation whether the student is accomplishing the steps.

GCA/ILS Monitoring

Simulators that are intended to train students in instrument flight usually have a display that depicts the geometry of a GCA (ground-controlled approach). The final approach and the glide slope are usually shown with the aircraft symbol and track superimposed on each (see Figure 9). The instructor can determine either from a graphic scale or from a numerical readout how much the student is deviating horizontally and vertically. The instructor can then provide the simulated GCA operator's instructions to the pilot. More advanced simulators automatically display the instructions on the page, so the instructor only needs to read them. Automatic voice instructions are also available, as on the F/A-18 OFT.

A form of APM is required for the computer to evaluate the location of the aircraft with respect to the correct approach path and to display the proper GCA instructions. However, no specification requires an automated evaluation of the approach or a score representing degree of excellence. The instructor, of course, can determine visually from the track on the display whether the approach was within subjectively determined limits.

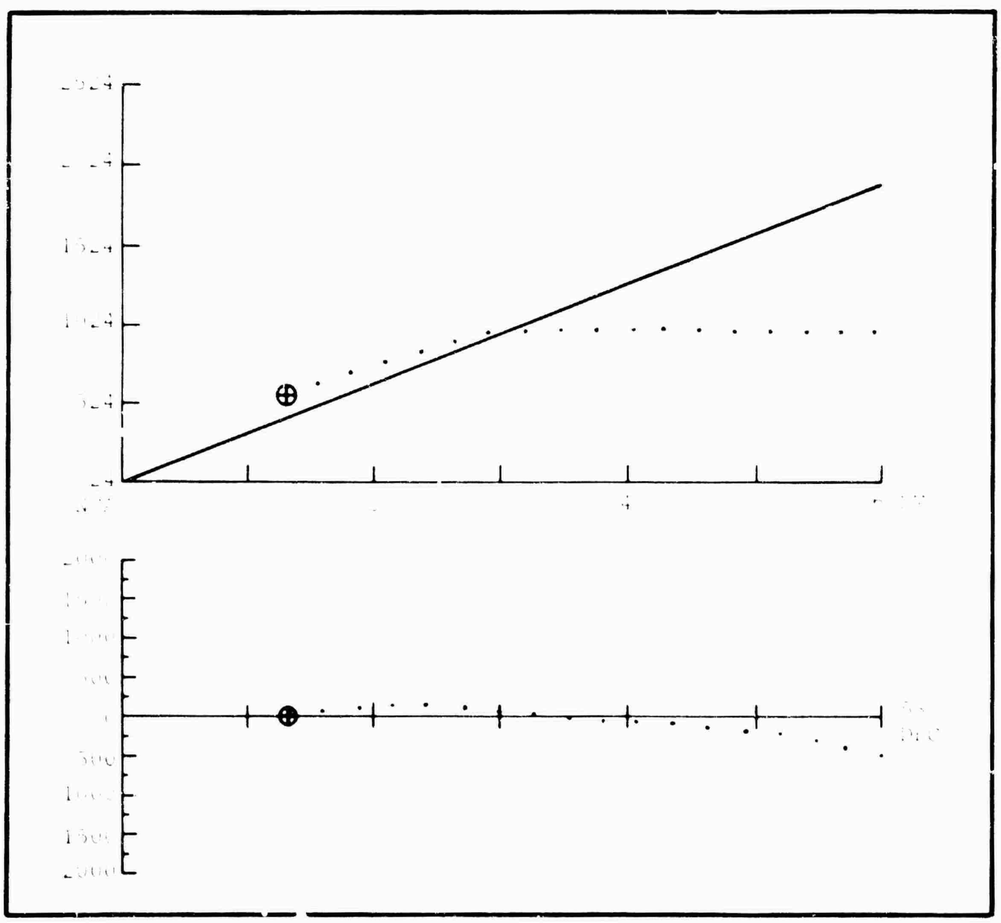

Figure 9. Typical GCA/ILS Display

Some simulators use the same type of display for ILS (instrument landing system) approaches, except that operator's instructions, of course, are not included. Alternatively, a repeater instrument at the instructor station reproduces the ILS indications in the cockpit and enables the instructor to visually evaluate the approach. Like GCA's, no specification requires a computer-derived evaluation or score.

Time Plots

Some simulators have a graphic display that depicts certain parameters, such as altitude and airspeed, plotted against a time base (see Figure 10). This type of display is usually shown in an area of recurring flight data, sometimes called the "reserved area" or the area for "supplemental data".

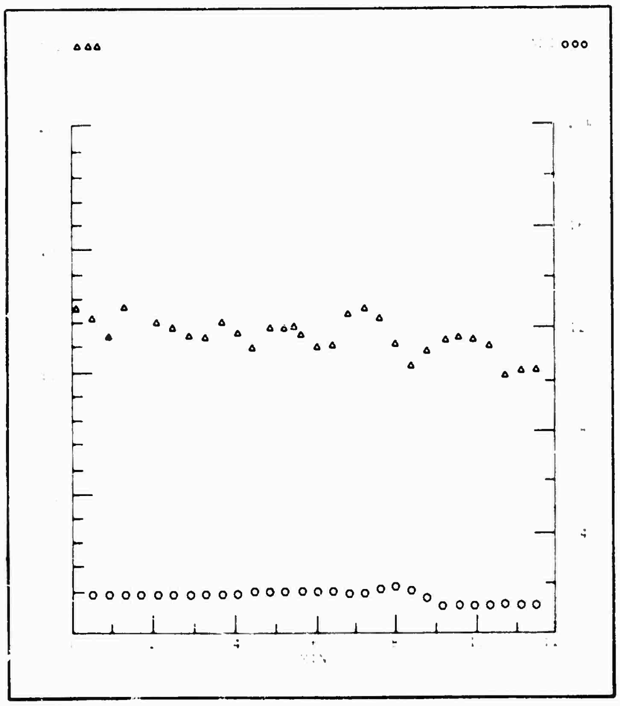

Figure 10. Time Plot Display for CH-53D OFT

The purpose of this display is obscure. It provides a brief graphic record--the period covered is usually around 10 minutes--but no provision is made to include a reference value or tolerance. One suspects that it is a carry-over from an out-of-date concept. While it is computer-derived, it falls far short of being an example of APM.

Terminal Conditions

Simulators for carrier-based aircraft sometimes have a display or printout that provides data related to the landing on the carrier deck. The A-6E Night Carrier Landing Trainer (NCLT) has devoted half of its Performance Evaluation Page to a Terminal Conditions Display which automatically records nine parameters, such as the wire caught, hook-ramp clearance, lateral distance from centerline, etc. (see Figure 11). The instructor is able to print the data for later use in the post-mission critique.

TERMINAL CONDITIONS

	WIRE CAUGHT	4
	HOOK-RAMP CLEARANCE (FT)	16.0
	LATERAL DIST FROM C L (FT)	-1.4
	RATE OF DESCENT AT CONTACT (FPS)	-5.9
	PITCH AT CONTACT (DEG)	9
	ROLL AT CONTACT (DEG)	1
	YAW AT CONTACT (DEG)	6
	BALL POSITION (WIDTH)	0.00
	DRIFT RATE AT CONTACT (FPS)	1.6
1	PRINT TERMINAL CONDITIONS	0

Figure 11. Terminal Conditions Display for A-6E NCLT

In other simulators a similar display is sometimes provided for the terminal conditions pertaining to landing on a runway. In the F/A-18 OFT the Landing Data Display, which is not automatic but must be called up by the instructor, has a dual-purpose display, half of which is devoted to carrier-oriented parameters and half to runway. The parameters are mostly the same, except that those for a runway include "distance from threshold" rather than "wire caught" and "hook-ramp clearance".

In the F/A-18 OFT, the display lists the optimum values for the carrier-landing parameters. The optimum hook-ramp clearance, for example, is stated as 14.1 feet. After a student has completed a landing, the instructor can compare the actual values with the optimum ones.

As observed previously, it appears that APM could be called on to go one step farther and provide a qualitative assessment of the student's performance. Since the optimum values are known, all that remains is for the users to determine the range for satisfactory achievement. The computer would do the rest.

Ejection Data

A display similar to terminal conditions displays is the ejection data display, which presents to the instructor the essential information regarding an ejection, if the student simulates one. In the F/A-18 OFT the display reports the indicated airspeed, altitude, vertical velocity, bank angle, and pitch angle--all of which are relevant to the success of the ejection--and then, in a succint demonstration of APM, concludes by answering with yes or no the question "Successful?"

Event Printout

Another feature related to performance

measurement but with an obscure purpose is that referred to in specifications as "event printout". In the A-6E OFT, for example, this program automatically prints out the time of occurrence of 18 flight-related events. The events include takeoffs, gear up, flaps/slats up, stores release, master caution light illuminated, landing touchdown, and others. For some events, the associated airspeed, altitude, and angle of attack are also printed out. The printout is made either on the parameter recording sheet, in the Remarks column, or separately if parameter recording isnot in use.

Presumably the instructor will use the printout as an aid in critiquing or evaluating the student. If the event printout program is used in conjunction with parameter recording it can assist the instructor to reconstruct the mission and interpret the strip charts. Its usefulness alone is questionable.

USER OPINIONS

Representative user opinions about APM are difficult to obtain. Instructors who regularly man the instructor stations are the most knowledgeable persons about the usefulness of the different variations, but a consensus can be obtained only by questionnaires or personal interviews--an impracticable approach in view of the widely scattered locations of most simulators. The two existing A-6E WSTs are located as far apart as NAS Whidbey Island, Washington, and NAS Oceana, Virginia. The A-10 OFTs that have been the longest operational are located at Davis Monthan AFB, Arizona, and Myrtle Beach AFB, South Carolina. The EA-6B WST is at NAS Whidbey Island and the A-6E OFT is at MCAS Cherry Point, North Carolina. A comprehensive survey covering such locations would be very costly and time-consuming.

Another problem is the fact that the newest simulators have the most complete suite of performance measuring features, but some of these simulators are too new for a definitive assessment. The F-16 OFT, the A-6E OFT, and the F/A-18 OFT are very current simulators with many examples of APM; unfortunately none has been operational long enough for the users to have acquired a body of opinion.

In the absence of a thorough survey of instructor's views, the observations and general opinions of a variety of user representatives have been obtained, mostly by telephone. These persons include instructors and device operators, supervisors of training at the base/station level, and staff officers at the headquarters level who are responsible for planning simulator utilization. They all have considerable experience in flight training and the use of simulators, and they have varying degrees of knowledge about the types of APM available.

Checkrides

From the available opinions it must be concluded that checkrides are used very little, even with the simulators that have the most advanced capability. The general range of use, among the different simulators investigated, is from zero to very infrequently.

The reasons for non-use are complex. In one case, only one checkride was delivered, of ten originally required by the contract; the remaining nine were omitted in return for other "considerations". The user was instructed in how to develop his own, but to date he has not done so. To compound the problem, the one checkride delivered was more of a demonstration of the capability than a mission tailored to the user's needs.

In another case, difficulty in operating the program has been the principal reason for lack of use. All of the leg ends are defined by latitude and longitude, so if the student does not come acceptably close to the specified location, the instructor must intervene, which is a frequent occurrence. In this simulator he slews the aircraft so as to achieve the leg end. This process not only is cumbersome but also it invalidates the scoring.

It can be predicted that any checkride program that is difficult to update will tend toward disuse. Usually specifications require that program updates, including changes in display pages, be able to be accomplished via Plan Mode (a term used in U.S. Navy specifications). Ideally, Plan Mode should be easily operated by instructors or maintenance personnel. If it is not (often only because the instructions are unclear), the checkrides will become static, out-of-date, and unused.

Underlying all other reasons for checkrides not being used is the probability that instructors subconsciously resist computer evaluation of a student. Why this attitude should exist--whether it is based on ignorance, prejudice, or parochialism--is not within the scope of this paper. But to some degree it exists. Possibly a contributing factor is the feeling, at the base or station level, that the requirement for checkrides in the specification originated elsewhere.

Automissions

Relatively few operational simulators have automissions, therefore the user opinion of this feature is limited. The available evidence is that acceptance and employment of automissions will be similar to those of checkrides, although possibly there will be better utilization of automissions because the instructor is more in control, particularly through his ability to vary the difficulty of the mission based on his judgment of the proficiency of the student.

Monitored Maneuvers

Since the monitored-maneuver approach originated at the U.S. Coast Guard Aviation Training Center, at Mobile, Alabama, where the simulators involved will be located, it can be expected that the users will be reasonably pleased with it. The simulators are over a year from delivery, however, so how much it will actually be used is to be determined; but it is anticipated that this form of APM will be an integral part of the Coast Guard's training syllabus.

Semi-Automated Performance Measurement

No information is available on how much semi-automated performance measurement is used in the A-4H and N simulators. In view of the demands that this program makes on operators, it it unlikely that it is used much.

Parameter Recording

Parameter recording is another example of APM that is used either not at all or very little. The reasons for non-use are more apparent than for checkrides--parameter recording is difficult to operate, unless the number of parameters monitored is kept to a minimum; and the results require analysis and interpretation by the instructor, unless the maneuver is quite simple. Parameter recording could be used, for example, to monitor the g-schedule during a loop, or to monitor the rate of turn during a TACAN arc. It could not be used easily during a series of acrobatic maneuvers or during an entire instrument approach. The statement was made by an interviewee that parameter recording is more applicable to basic flying training than to advanced or tactical training. That may be an accurate observation.

In one simulator, the A-6E Night Carrier Landing Trainer (NCLT), it has been reported that parameter recording is used extensively. The mission of the NCLT is to enable a student to make repeated carrier approaches and landings. The parameters to be monitored can be preplanned on a CRT page and entered simultaneously at the beginning of each approach, and the results are displayed and later printed on a two-minute strip recording. Thus, the mission of the trainer is simple and its parameter recording capability is compatible. An additional feature that may influence the user's opinion is the ability of the instructor, at the completion of each landing, to display the strip recordings to the student via the visual system at the trainee station, i.e., in the cockpit.

Other Forms of APM

The other forms of APM discussed previously--weapon scoring, procedure monitoring, GCA/ILS monitoring, etc.--are generally simpler, easier to operate, and easier to interpret than the full-mission programs such as checkrides, automissions, and parameter recording; and they are well accepted and extensively used, with some exceptions.

Weapon scoring is used because it provides an assessment, usually graphically, that the instructor is unable to make himself. Likewise, procedure monitoring is used at a remote instructor station because the instructor has no other way to determine what the student is doing in the cockpit. GCA/ILS monitoring is accomplished simply and graphically, and consequently is well accepted. Time plot displays, as described in the foregoing, are usually contained in the reserved area and hence are always present, but if they were assigned to a separate display, it is likely that they would never be used. Terminal conditions displays are used when they are generated automatically; when they are not they are often overlooked. The use of event printout is usually related to the use of parameter recording, thus it suffers from the same problems.

CONCLUSIONS

Many conclusions can be drawn from a study of APM. The most obvious one is that the Government spends a great deal of money procuring programs that are used very little. However, it does not follow that less emphasis should be placed on APM. There are many ways in which APM can assist and improve training; the direction of effort should be to insure that the money is spent effectively.

It appears from the language in specifications that the Government is unsure about what it wants. In many cases the description of required capabilities is unclear. "Boilerplate" language is used that can be traced back to specifications many years old; the meaning was vague then and it still is. Furthermore, inconsistencies and redundancies exist within the same specification.

As a first step toward being more precise about its needs, the Government should standardize its terminology and publish a glossary of simulator-related definitions for use in all specifications. The term "automated training exercise", for example, should have an exact meaning, or if "automission" is used instead, it should mean the same to the Air Force as to the Navy. Or, alternatively, a more descriptive term should be devised and made standard.

The subject of standardization of "instructional feature requirements", which includes many other features besides APM, has been addressed by Pohlmann, Isley, and Caro, and the development of "design guides" has been proposed.(5) Some recent specifications contain design guides, although they do not cover APM features as thoroughly as might be desired. The concept of design guides is subject to debate--if it is too rigid it could discourage initiative and innovation--but at least it would provide a base of a common, understandable terminology.

As the second step in defining its needs, the Government should conduct an organized study, or a series of studies, of the uses of APM. The principal purpose of such research would be to determine which of the different variations of APM are the most useful. The questions to be answered are simple: Should checkrides and parameter recording both be procured on an OFT? Are automissions cost-effective? Should the use of tolerances be abandoned in favor of more sophisticated, comparative scores? Should procedure monitoring be used with on-board instructor stations? How many of the marginal versions of APM--terminal conditions displays, time plots, event printout--should be procured?

The fact that a feature is little used is not proof that it has little potential value. In many cases, the use of instructional features depends on the training and motivation of the instructors. The fact that instructors frequently do not know how or when to use "advanced simulator training features" has been commented on by Caro in a report entitled Some Current Problems in Simulator Design, Testing, and Use(6). Probably their ignorance or disinterest is greater in the area of APM than in any other general feature.

Perhaps what is needed more than any single action is better communication and coordination among the procuring agencies and users. Too often the mistakes made with one simulator are repeated in others, through specifications that, in the field of APM, have simply been copied from preceding ones. Even if serious mistakes have not been made, there are lessons learned in every design that are not being passed on to succeeding ones.

A fall-out from better communication would be more appreciation at the base/station level of the ways in which APM can assist instructors. During training sessions there are many demands on simulator instructors; they would benefit from the computer's assistance if they better understood its capabilities.

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Tactical Training Methodologies for Ground Forces Command Center and Their Implementation

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USE OF WORD PROCESSING IN DATA DEVELOPMENT AND REVIEW

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ABSTRACT

With the widespread availability of word processing within businesses, the government and the homes of many Engineers, it has become increasingly apparent that this tool could be used effectively to reduce the high costs of contractual data preparation and review while simultaneously improving the quality of this data. This paper addresses the use of word processing on an NTEC program. The primary objective is to reduce the total cost and elapsed time of the preparation-through-acceptance (PTA) cycle of the contractual documents.

INTRODUCTION

During the early stages of an NTEC study progam (in which deliverable documentation consisted primarily of reports and tabular data) the use of a microcomputer based word processing system was considered as a cost effective approach that would entail minimum cost and schedule risk.

The approach was considered appropriate due to the extensive review comments anticipated as well as the significant updating of the data that would occur over the life of the program. Although block and functional flow diagrams were also developed during the study they constituted a relatively small percentage of the total data package.

Since normal trainer developments also share some of these characteristics, it was evident that the results of this effort could be applied to these trainer programs as well.

Our primary hypothesis is that much of the data development time could be reduced if the PTA cycle could be reduced. Even though most of the data items prepared under a typical trainer contract are Category II or III (data items that would normally be prepared by the contractor and require only reformatting or can be delivered outright), the practical aspects are that even if the data is prepared for use by the contractor, its submission and subsequent rework for approval requires a significant expenditure of effort due to the length of time (and hence cost) between generation and approval. Shortening this cycle would make the data more meaningful to both the contractor and NTEC and hence reduce the total cost.

DATA PREPARATION AND REVIEW

Before discussing the results of this approach it is necessary to examine the data PTA cycle to gain a better understanding of what is to be accomplished. Figure 1 shows this typical cycle. Both the time spans and the actual "roadmap" will vary from item-to-item, contract-to-contract and contractor-to-contractor, however, the essential processes do not vary widely. Note that over 30% of the elapsed time between the completion of the rough draft write-up and receipt of the NTEC comments is in distribution and mailing. Only about 25% of the time is spent with the document in the hands of either the originator or the NTEC recipient.

The approach to be described concentrates on the following specific areas:

1. Initial data generation
2. Government review and submission of comments to originator
3. Incorporation of review comments

These areas indirectly or directly account for the majority of the time spent in the PTA cycle. Not specifically addressed were the areas of.

1. Contractor design/document review procedures
2. NTEC review-procedures
3. Formal Contractor or Government handling procedures

Through the use of word processing and data transmission equipment significant improvement in the PTA cycle time was achieved without disrupting organizational procedures.

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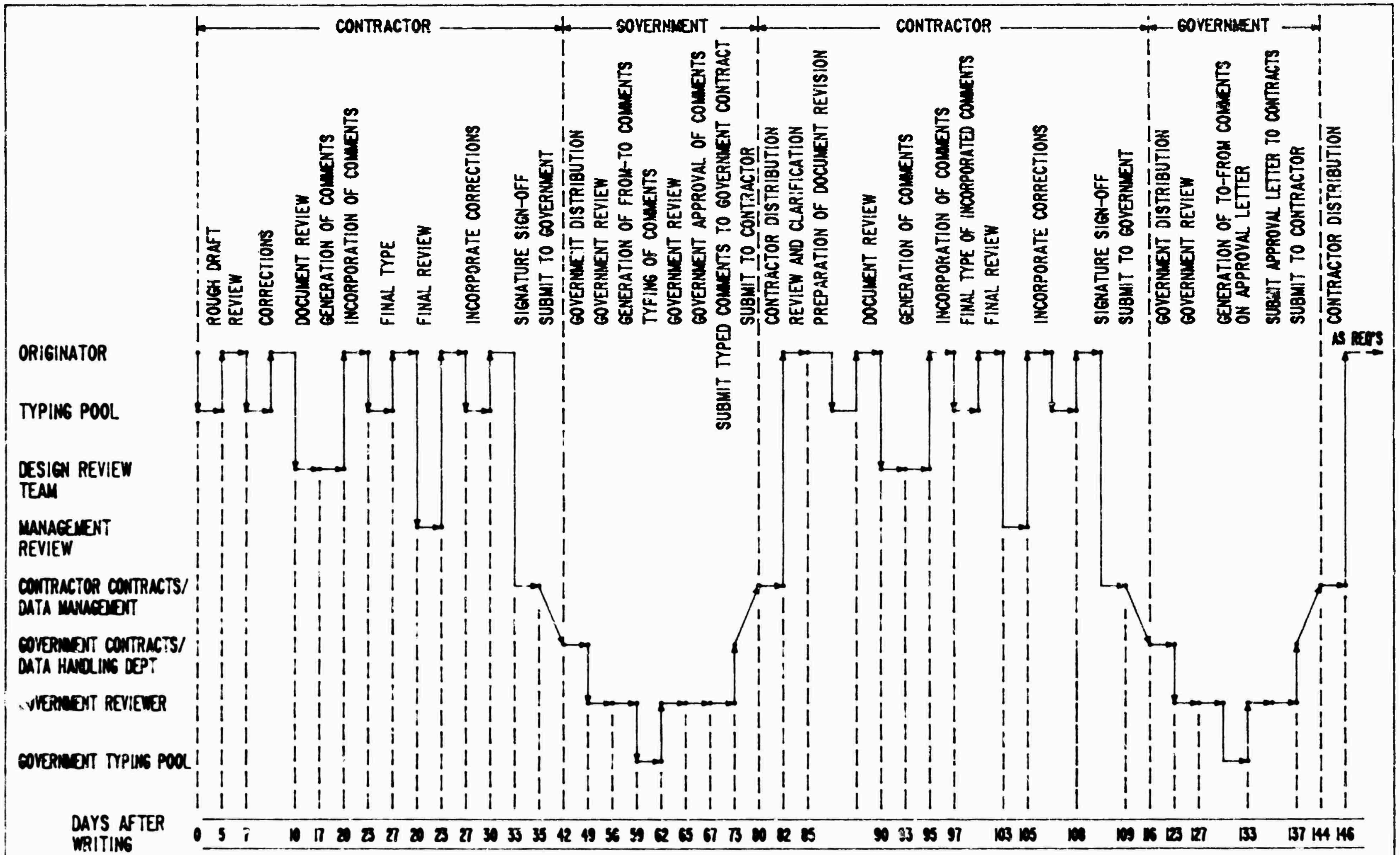

FIGURE 1 TYPICAL DATA DEVELOPMENT SCHEDULE

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Some processes were changed and/or expanded in order to accommodate the handling of computer diskettes. While basic generation and review procedures were left unchanged, a procedure was developed to contractually protect both the contractor and NTEC when data was being developed or passed on-line from computer to computer.

Initial Data Generation

To assist the originator in developing the data, a commercially available microcomputer, word processing software, printer and telephone modem were purchased under contract. Training of the originator's secretary enabled her to support the initial data preparation and to reduce the dependency on the direct charge (and fairly inflexible) typing pool. The modem was provided so that data prepared on the microcomputer could be passed directly to/from the word processing equipment used by the typing pool. Some difficulties were encountered in attempting to complete this interface with the typing pool equipment. As an interim measure, files were established on a remote time share computer system. These files were read from, or written into, by both the microcomputers and the typing pool equipment. (A vexing problem developed in the way in which various computers and word processing software treat "carriage return/line feeds". This is discussed under lessons learned.) At the time of this writing, methods were being evaluated for upgrading this communications method.

A significant portion of one of the deliverable documents (some 200 pages of tabular data) had previously been prepared on the remote time-share computer. This data was down-loaded to the microcomputer. The originator was then able to edit the data file directly and incorporate it into the document. Had this capability not existed, the entire document would have had to be essentially re-generated (the edits performed were substantial and not readily describable to a typist). By using this previously generated data file, the originator and editor had to concentrate only on the changes, not the entire document. The originator completely revised these tables in about two days (The original typing, editing and reviewing took more than two weeks.). Since many deliverable data items consist of portions of previously developed data, this extraction and edit process can be used effectively to reduce the time and cost of developing other data items.

Due to the problems encountered in directly transmitting to/from the contractor's word-processing equipment, only the microcomputers were used for developing the data delivered under the contract. Accordingly, some format requirements were relaxed, or waived, in order to accommodate the process (the primary limitations were split page format, relocating artwork, and the use of underlining and change bars.)

The general process used by the originator was to have the document typed by his secretary using the microcomputer and wojrd processing software and then mark up a printed copy of the rough draft for editing on the microcomputer. Editing was performed either by the originator's secretary, the editor or by the originator. The data was stored on 5-1/4 inch floppy diskettes which were formally "cycled". (Diskette cycling is discussed in Appendix A.)

In accordance with the contractor's Engineering procedures, a design review was conducted using printout's of the data package. The majority of the design review team generated comments in a normal manner: i.e. FROM/TO changes. One team member incorporated his comments directly onto a copy of the original diskette. His changes were indicated by underlining changes and additions. Blocks of deleted data were indicated by the string "**deleted**". Individual words were merely deleted. After review of his comments, his diskette was copied and the deleted phrase removed with the microcomputer's editor. This process saved the reviewer a significant amount of time and effort in writing his comments. It also saved the originator time incorporating them. This process did, however, require the reviewer to have access to a compatible computer system and know how to use it.

In another case, the reviewer transmitted the data to the remote time-share computer, and then incorporated his comments on that data file. This file was transmitted back to the microcomputer for incorporation into the complete document. This latter process was used once when the microcomputer was in use for long periods of time and also when the reviewer was out of town but had access to a data terminal and telephone.

Government Review And Submission Of Comments To Originator

By far the most beneficial aspects of this approach are in the Government (NTEC) review, contractor update and resubmission process.

NTEC's Project Engineer was provided a microcomputer, printer telephone modem and word-processing software identical to that of the contractor. To expedite computer-to-computer communications between the contractor and NTEC, the remote time share computer was used as a 24 hour intermediary to which data files were sent and retreived. This process was used to allow communication via TYMNET which has "cleaner" data lines than commercial long-distance voice grade lines.

In some cases, data was submitted informally for review, updated and then formally submitted. In other cases the data was prepared and submitted formally, without an informal review. In both cases, diskettes and a printout were included in the submission, and in both cases NTEC comments were made directly on the diskette by underlining changes and additions and, by marking deleted blocks of data by the string "** deleted **". (This is the same process used by the originator). A copy of the updated diskette was returned to the contractor for formal re-submission. In some instances, advance comments were also transmitted back to the originator via the remote time-share computer. By providing equipment on which the NTEC reviewer can make changes directly on the submitted diskettes, a significant saving in time and cost for both the Contractor and NTEC was achieved.

Not all comments were incorporated by the reviewer. Some required additional data and/or restructuring by the contractor. However, the ease of incorporating this data greatly enhanced the process. (As with the Contractor's review, the data was never completely retyped, therefore only the areas of change required an extensive review.)

There were instances when the contractor was meeting at NTEC and incorporated on-the-spot changes or additions to the data package by locally updating a diskette. The data was then sent over the telephone to the contractor's microcomputer for formal resubmission - all within a matter of hours.

This process virtually eliminated the need for "FROM-TO" comments and enabled NTEC's Project Engineer to be more specific in his comments.

Incorporation Of Review Comments

Many of the aspects of incorporating the reviewer's comments were discussed previously. However, it is significant that it was never necessary to retype major portions of the document and the reviewers comments were usually clear and unambiguous since most of them were incorporated directly.

In some instances the data diskettes were transmitted back to the remote time-share computer for integration. In most cases, however, the originator and his secretary made all of the changes not already incorporated by the reviewer.

Although a direct diskette to diskette submission of data requires hardware and software compatibility, the use of an intermediate, remote, time-share computer, or standard RS232 communications link could be used for the transmission of data for review purposes. Imbedded printing and format commands are usually not compatible between different word processing software, therefore, the review document data would have to be sent without these commands. Where incompatible hardware/software exist, the diskette would not be submitted with the data package.

EVALUATION

Since the documents had not been developed using both this approach and a more conventional process, an auditable FROM-TO comparison cannot be made. However, based upon the experience of the Contractor, time estimates have been prepared for three of the data items. Table I shows these results. At the time of this writing, many start-up problems had been coped with and growing pains felt. A cross-section of technical and administrative documents had not been submitted from which to draw financially auditable conclusions on the general use of this approach. There is no doubt that there will be a small number of documents in which either the content, format or the method of generation is incompatible with this approach.

TABLE I COMPARATIVE TIME

CDRL ITEM	PAGE COUNTS Text	Tables	Ilst.	TIME (HOURS) Est.	Actual
1	31	49	6	202	147
2	2	77	29	284	135
3	201	117	57	1000	360

Both NTEC and the contractor are sufficiently confident of this approach that the majority of the data items on several contracts will be prepared and processed using many or all of these techniques.

LESSONS LEARNED AND PROBLEM AREAS

Although this approach has proved to be cost effective, there are several areas which must be considered:

1. Since this process relies heavily on direct engineer-to-engineer communications, document control procedures are necessary to protect both the Contractor and NTEC. A preliminary set of procedures has been developed for use by the Contractor to ensure that

control is maintained over the data submitted and that committments are not made unofficially. A summary of these procedures is contained in Appendix A.

2. At the time of this writing, the most appropriate documents to address in this manner appear to be:

a. Correspondence
b. Statements of Work
c. Specifications
d. Status and Progress reports
e. Technical reports (those with minimum artwork and a minimum of mathematical equations)

Investigations are currently underway to determine how much of the typical ILS data can be effectively handled with this approach.

3. Many remote, time-share computer systems may not accept a "string input mode" but are limited to lines of less than 250 characters. Since many word processing systems are not line-oriented, they may not be compatible. This problem has been experienced and at the time of this writing is under investigation.

4. Micro-computers have limited memory and somewhat limited word processing capabilities. The most effective use of them is in the preparation and review of data which can be broken down into 15000 to 20000 character segments. Although it is more effective to use larger word processors for the final output, microcomputers offer the advantage of being more "user friendly". This capability is valuable in the preparation of technical data which may require computational ability and/or data base manipulation. In addition, it is typically more cost effective to procure computers than word processors for Engineering groups.

5. Most of this process can be accomplished through the use of remote time-share computer systems exclusively. We have found that reliability is higher, speed is increased and total costs are less using local microcomputers or local multi-terminal processors. In any case, the terminal at which the operator is located should be "smart", have at least 2K to 4K of local character memory and support diskettes. The system currently employed is shown in Figure 2.

6. Direct computer-to-computer communications using conventional voice grade telephone lines has not been found to be satisfactory at speeds over 30-60 baud. Communications accessed via TYMNET are satisfactory to 300 baud over a conventional voice grade line. A local call over a data line is satisfactory to 1200 baud. On some computer systems the CRT refresh time may be sufficiently long that some data is missed if transmissions over 600 baud are attempted. Selection of the communications software should take this into account. The software should provide a "PAGE" vis-a-vis "SCROLL" mode of operation to get around this problem.

7. Time-share computer systems typically provide 24 hour backup. This protects the user from losing more than 24 hours of data. Micro-computers do not offer such protection, therefore it is mandatory that diskette cycling be used. This cycling procedure, which is discussed in Appendix A, involves maintaining at least three copies of each diskette, the most recent version of which is copied onto the oldest version.

8. Format requirements found in many Data Item Descriptions (DID's) are not generally compatible with this approach. The emphasis must be placed on legibility and accuracy rather than format. The primary problem areas are:

a. Split-page format
b Boldface and underlining
c. Location of non-textual data such as
artwork, photographs, etc.
d. Character font
e. Tabular formats

The more sophisticated word processing systems can usually accommodate these requirements, however many cannot interface with any other system and many require that format commands be permanently imbedded in the text. These characteristics significantly reduce most of the benefits derived from this approach. Whether these characteristics are "MUSTS" or "NICE TO HAVE'S" must be seriously reviewed by both the contractor and NTEC.

SUMMARY

The use of this approach for developing deliverable documentation shows considerable promise in significantly reducing both the time and cost of data preparation.

Although the project is just underway, most of the objectives are being achieved. The status at the time of this writing shows:

1. A 50% - 75% reduction in turnaround time is being realized primarily due to the direct incorporation of comments, versus the conventional "TO-FROM" mechanism.

2. The documents show a significant increase in accuracy due to a reduction in the number of "re-types" and a significant decrease in the preparation lead time. In some instances, the formal submissions

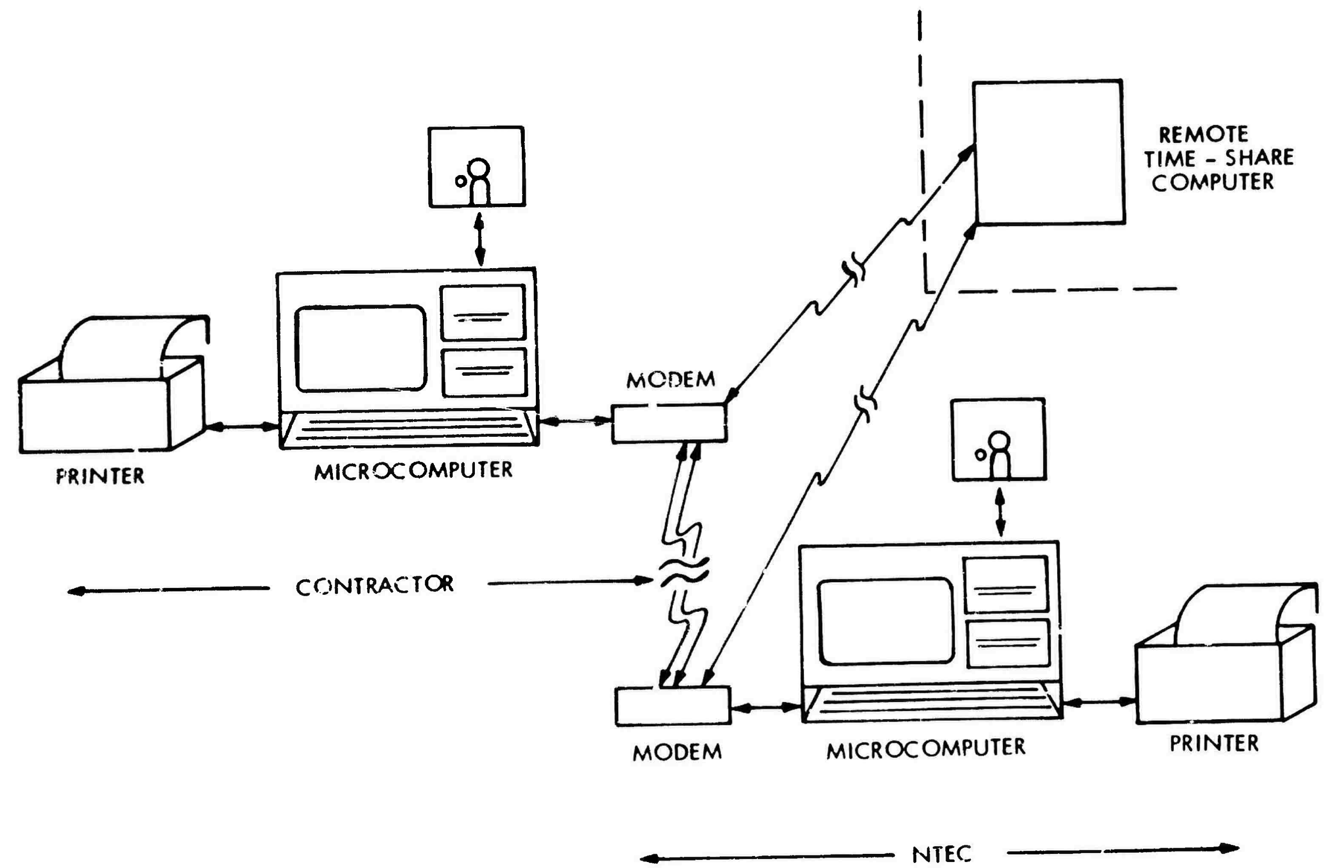

FIGURE 2 MICROCOMPUTER HARDWARE CONFIGURATION

contained data only a few hours old.

3. Control and handling procedures were developed to ensure that the potential informality did not compromise NTEC or the contractor.

4. Format guidelines were relaxed with emphasis being placed on legibility and technical content.

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APPENDIX 1

COMPUTER DATA TRANSFER PROCESS

SUMMARY PROCEDURE

BACKGROUND

With the advent of microcomputers and word processing, documents may be delivered on diskette and/or transmitted electronically directly to the receiver. This procedure defines the process for computer - computer communications and delivery of documentation on diskette between the customer and the Contractor. This procedure is not intended to cover the submission of contractual letters.

FORMAL SUBMISSIONS

General Policy

Other than the medium of submission, formal submissions require the same procedures that are currently in effect. The following procedure documents those aspects which are peculiar to the magnetic medium process.

1. Originator. Prepare documentation in accordance with the (Contract Data Requirements List (CDRL) requirements utilizing blank formatted diskettes. Verified backup diskettes shall be prepared by the originator for Data Management. Unless otherwise approved by the Engineering Manager, a complete printed copy of the (submittal diskette) data shall be prepared for Data Management, whether or not the submission requires a printed copy. Prior to preparation of the diskette, the originator shall obtain a control number from data management and shall format the diskette with that control number as its name. Since diskettes may contain more than one document, the TD number shall not be used as the control number. The first "page" of diskette data shall contain:

- Contract number
- Item (e.g. CDRL number)
- title
- revision
- File name of the data on the diskette
- Date of submission
- Originator
- Computer model, serial number and drive number
- Operating system utilized
- Program utilized (i.e., Lazywriter, VISICALC, etc)
- Data Management Control Number
- Diskette Cycle (A,B, or C)

2. Data Management. Record, control and submit diskette data in accordance with current established procedures. Maintain files of control number, diskette first "page" data, diskette and printed data. Ensure accuracy of control data and diskette first "page". Ensure that backup diskettes are readible (i.e., perform a LIST on the computer). The diskettes retained by Data Management are considered the masters and must be controlled as such. The printed copy, not the diskette, shall be routed for signature.

Updating Formal Submissions

Data to be updated shall be generated as follows:

1. Originator. Obtain a copy of the master diskette from Data Management. This copy shall be used as the working master for update. Data Management shall asign a control number revision for incorporation into ~~the~~ the first "page" data. all first "pages" in last - first sequence shall be retained on each update. The updated diskette shall be separately saved and handled. Submission to Data Management shall be handled the same as formal submissions (See above).

2. Data Management. Except for the requirement to maintain separate diskettes for all document revisions submitted, the procedure defined above is to be followed:

NOTE: Multiple revisions can be contained on the same diskette if desired, however each submission shall be on a new diskette and all prior diskettes shall be retained. Decisions to discard prior copies must have the approval of the Engineering and Program Manager. Unless specifically exempted, sufficient diskettes will be retained to ensure that copies of all revisions are contained on one or more of the master diskettes.

3. Diskette Cycling. To minimize the possibility of loss of valuable data, Data Management shall institute a policy of "Three Diskette Cycling". The purpose of diskette cycling is to continually maintain the three latest revisions of diskette data such that recovery from either erroneous updates or diskette damage is no more than one revision away. A summary procedure for cycling is as follows:

a. Originator. For each document (or contract), prepare three formatted diskettes labeled (internally) A,B and C. Each time an update is made, the originator obtains the cycle log from Data Management and copies the updated version onto the lowest cycle diskette which then becomes the current Master.

b. Data Management. Establish and maintain the cycle log for each diskette.

BEST AVAILABLE COPY

File Names.

File names shall be used that incorporate the revision as an extendion, e.g., "CDRLA001/R01". CDRL A001 is at Revision 01 on that fi . Each update shall be made by renaming the current file and revision. Where more than one revision is contained c. a single diskette, the new revision shall be copied. This will facilitate maintaining control utilizing the directory listings.

Customer Listings.

Due to its cost effectiveness, the customer should be encouraged to submit review comments by actually up-dating a copy of the document diskette. He should identify his changes by underlining his changes or by writing "***INITIALS" in the margin. This process will expedite handling, increase accuracy and reduce cost for both the customer and Honeywell. Comments received this way must be formally acknowledged to the customer by sending a printout of either the directory or the data of the updated diskette as received by the Contractor

Electronic Submission

There will be times when it will be expedient to electronically submit data in lieu of the mails. This process shall be utilized only for the submission of working or advance copies and sh. l not be used a. a substitute for formal submission. Advance copy transmission shall not occur until document approval has been received. During transmission, the first page of data must define the document as an advance or working (unofficial) copy unless specific prior approval for alternate hand'ing is obtained.

INFORMAL (ENGINEERING) SUBMISSIONS

General Policy

Informal data submissions shall be handled in accordance with the current Customer Engineering Letter (CEL) policy except so far as format is concerned. The general requirements for handling diskette data shall be as described in above. Systems Engineering is responsible for the submission of such data and for performing the diskette handling management functions defined above. Where data is being developed on-line, it will be documented as a telecon.

AD P000177

BASELINED SOFTWARE CONFIGURATION MANAGEMENT: AN AUTOMATED APPROACH

by

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ABSTRACT

Software intensive training equipment has become the normalcy for current and foreseeable future training equipment procurements. Software support for these software intensive devices is an ever increasing burden which must be undertaken by the most efficient manners possible. Aid for modification software support has been addressed by software tools developments that facilitate modifications, testing and baseline configuration management of these software intense devices. This paper addresses the phase of software support, configuration management, which is often neglected or given too little priority until the day of reckoning arrives; the software configuration loss or error. A tightly controlled software configuration of a software intensive device is perhaps as important as the configured software itself. Software configuration control is addressed in this paper as a crucial element of the life-cycle support effort. A configuration control methodology which maintains visibility and complete software modification audit capabilities is discussed. An automation of this methodology is presented which affords complete and accurate control for modification processing of a baselined software configuration. The entire automated process extends from the receipt of a modified software component to the installation and tracking of a newly configured and tested software release. Additionally, the capabilities for multiple device software configuration tracking with a centralized procedure and support environment is explained based on actual procedures currently in use at the NTEC Software Support Facility (SSF) which is located at the NTEC Annex at Herndon, Orlando, Florida.

INTRODUCTION

The Software Support Facility (SSF) at the Naval Training Equipment Center (NTEC), Orlando, Florida, marked a first at NTEC for providing software support capability with in-house resources for major training devices.(1) The design concept of the SSF was to centralize the software support functions of remotely located software driven training equipment. Utilizing remote communications equipment such as remote job entry (RJE) and time share terminals, on-site support personnel as well as SSF personnel could work in a combined effort to accomplish software modification implementations. Centralized software support at the SSF, however, has evolved from providing software modification support to providing a concentrated software support resource with which any user or activity, regardless of location, can perform modification support efforts at the software baseline change level.

This service function which the SSF has undertaken involves primarily software modification tool support, software baseline configuration management and program processing, and a nucleus of software "smart" engineering staff to assist any support user with generic trainer related software problems such as math modeling and real-time operation. Modification tool support involves the development and support of software procedures to aid in the change implementation processes such as remote communications procedures, test compilation procedures for the various supported resources within the SSF, baseline management support, and modification informational support. Software baseline configuration management is provided by the SSF configuration management group. This group invokes a software configuration management discipline while utilizing an automated configuration control procedure that allows complete and accurate control for baseline modification processing. A strong software configuration management philosophy and strict adherence to that philosophy is required if the ever-increasing burden of true software baseline support is to be effectively addressed.

Centralization of software support facility type services is a viable and efficient concept for the baseline maintenance of software intensive training equipment. Further centralization of configuration control/management and automated program processing to a single point within the SSF environment ensures commonality of management, support procedures, and visibility among the many and various device software baselines which will be supported through the NTEC SSF services. Carried to this level of centralization, SSF resources and manpower need not be expanded in a wholesale fashion with each new software baseline brought under configuration management.

SOFTWARE CONFIGURATION MANAGEMENT OBJECTIVES AT THE SSF

The centralized software configuration management procedures exist to attain a definitive set of objectives. These objectives apply to the management of all configured baselines which are under the direct control of the SSF regardless of training system or device type and embedded computers. Basically, software baseline protection, maintainability, and development/modification visibility are addressed by the five established goals.

Objective 1.

The SSF configuration management will establish and subsequently protect the integrity of each software baseline identified for management under the SSF's configuration control procedures. Establishing a software baseline for a given system or

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device ranges in complexity from a simple audit for software systems developed under the guidelines of MIL-STD 1644A to a massive manpower consuming task of baseline recreation and verification as shown by the procedure in figure 1; the former case being that of most new procurements and the latter being that of older software systems, and even possibly newer systems where MIL-STD 1644A was not specified for development guidelines. Initial software baseline establishment is, therefore, more timely for MIL-STD 1644A developed software, but not impossible for the remaining software systems. Baseline establishment encompasses not only software verification but also structure preparation, format analysis, and all necessary management database development and loading; in short, establishment of all items identified by MIL-STD 1644 appendix A. Protection of the established software baseline is given the highest priority of all management functions and objectives because of the negative ramifications that are possible and probable when an established software baseline is not tightly controlled. Ramifications such as unauthorized modifications, authorized modifications to an incorrect baseline component, and even the loss of baseline components are all too possible. A tightly held configuration baseline affords maximum protection and confidence of possessing the correct baseline for a given system or device. Maximum baseline protection is accomplished by granting read-only access to all users while update access privileges are held only by the software configuration management group. Therefore, a software baseline impact can only be accomplished with configuration management knowledge and approval.

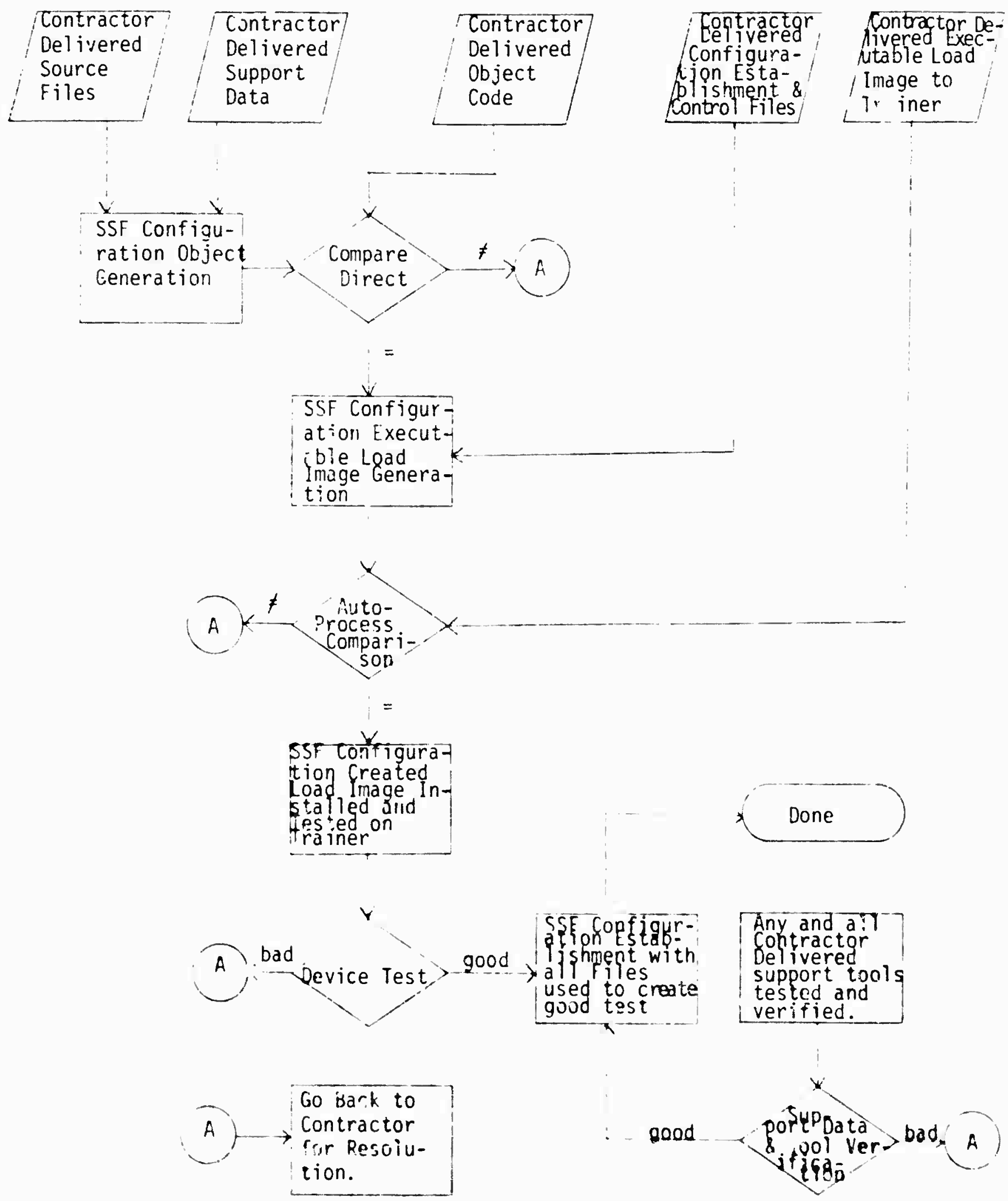


Figure 1. Software Baseline Verification Procedure

Objective 2.

Configuration management will provide for the ease and safety of implementing modifications to established software baselines. Ease of modification implementation is provided by the availability of software tools, utilities, and procedures used to edit, compile, process, etc., the baseline component whether it be a source/data file or documentation associated with the change implementation. Ease of modification is also enhanced by the various services provided by the configuration management group. Configuration identification is one such service. The currently configured baseline component is identified to ensure the modification is implemented on the correct component. Once identified, availability of that component is sampled. Possibly, the newly identified component is already undergoing change. If not, this component is "checked-out" or locked to the cognizant individual for work much as a library book is "checked-out". This service prevents simultaneous modification efforts on the same component where coordination would not be a factor. If additional work is targeted for a locked component, coordination among all cognizant individuals or activities is necessary to implement any concurrent additional changes. One change will not inadvertently supercede the other. A safety factor for modifying the configuration baseline is maintained by allowing new or modified components into the baseline account only through configuration management services under strict control by the configuration management group. Once a new or modified component is accepted into baseline control its existence and configuration impact are forever accounted for. Normal configuration acceptance of a component requires a documented work effort as well as an acceptable software design review finding. Unsolicited software component submissions cannot arbitrarily infiltrate the protected and configured software baseline account.

Objective 3.

Configuration management will establish and maintain configuration modification history/audit trails. How has the software baseline evolved from the original baseline establishment; or, how did it get here from where? The answers to this question are extremely helpful for maintaining full visibility for the software maintenance life-cycle. Also, software system maintenance is aided by enhanced modification history analysis capabilities. A configuration impact or modification to the current baseline is implemented via a parent/sibling relationship. An existing currently configured element, the parent, is referenced and modified to create a new element, the sibling, which will enter configuration tracking and pass through all applicable stages of status accounting until it possibly attains the parenthood status, in which case it would replace the parent from which it was produced or seeded. In any event, a fully automated history/ audit trail is maintained to track the evolution of a configured component from its earliest beginnings. This automated history/audit trail management allows the configuration management group to selectively report and/or completely reconstruct the executing configuration of a software system under automated configuration control at any previous point of its baseline history. The audit data retrieved in this manner would also show what, if any, software components were in the test phase at that time. The results are a full life-cycle visibility for all baselined software under automated configuration control.

Objective 4.

Configuration management will provide access services for baseline source/data files, listings, and all applicable support data. All currently active device software configuration baselines are maintained in a mounted, on-line status ensuring ready baseline access for all cognizant modification/development activities and individuals. The entire software source/data baseline for all supported software systems is available for read-only access to the cognizant individual maximizing access ease while minimizing potentials for baseline violations. For modification implementations a copy of the configured baseline component is easily retrieved into the implementor's work account where changes can be safely made. For software component development the implementor simply develops the component in the work account. At the completion of modification implementation or new component development the new software component is accepted into the configured baseline account only by the configuration management group after formal acceptance criteria have been met, i.e., software design review and quality assurance approval.

All listings such as compilation/assembly listings that are produced during automated configuration program processing will be cataloged and archived for rapid recovery upon request. Life-cycle support for a software baseline includes the efficient tracking and storage of all supportive data produced during the management of that baseline. Therefore, all such listings and data files are retrievable from the configuration management group upon request in a timely manner.

Objective 5.

Configuration management will provide maximum visibility for all software modification/development efforts managed under the automated configuration control procedures. Automated configuration management tracks a software system baseline from initial baseline establishment to the currently configured state. Automated configuration management tracks and manages all modification/development activities applied against a supported configured baseline. Automated configuration management relates the entire software baseline life-cycle evolution via parent/sibling relation chains. These facts enable the automated configuration structure of a supported software system baseline to yield various, informative reports concerning any phase of any or all components of any era of the life-cycle of the software baseline; in short, complete management visibility of the ever changing configured software baseline. This visibility is available as soon as the software baseline transitions to automated configuration management and remains available for the life of the supported baseline. For maximum control and visibility software baseline development as well as baseline modification should be managed via the automated configuration control procedures.

AUTOMATED SOFTWARE CONFIGURATION ENVIRONMENT

As software intensive devices continue to increase the training equipment inventory and as their operational locations continue to be scattered according to the operational needs of their users, the rationale for a single centralized software support facility becomes increasingly stronger.(1) Centralization of software support does not infer locale central to all devices nor does it infer a large central cadre of application programmers and analysts to supply the software support activity functions for all the various software intensive training equipment. The mission of the centralized software support facility is to supply a central set of resources to support the software modification/development activities wherever and with whomever they may be located. These software support resources include, but are not limited to, all necessary hardware, software, baseline storage and management, procedures, and expertise needed to comprise an efficient and responsive software support facility environment whose prime services are centralized program processing and configuration management.

Host Configuration Processor

The strengthening rationale of centralized software support also applies to a centralized software configuration management, centralized to the extent of common procedures, common database structure, consolidated baseline on-line storage, and a common point of contact for all modification/development/configuration management users: the host configuration processor. The host processor performs all user communications, both remote and local time share and remote job entry (RJE), automated configuration database management, baseline storage and control, and automated distributed processing management for all supported software system baselines. In the automated configuration environment the host processor is normally the only external communications link with the software support facility services. All users interface a common editor for source baseline modification/development, a common set of support services and tools, a common set of information resources, and most importantly a common procedural base for all supported and configured software system baselines. Program processing and management and device dependent functions are normally transparent to the software support facility user.

Distributed Processing Network

Figure 2 illustrates the distributed network through which the generic configuration processing system is able to complete the program processing functions. The host configuration processor is merely an automated manager and does not perform any native mode device dependent program processing such as compilations, assemblies, or link edits. Since these functions are distributed among various satellite device dependent systems the user interface remains responsive and user friendly while the communications unencumbered satellite systems of the network are busily and efficiently performing their native mode program processing functions. Several program processing functions may be active concurrently across the bank of satellite processors, none interfering with the others.

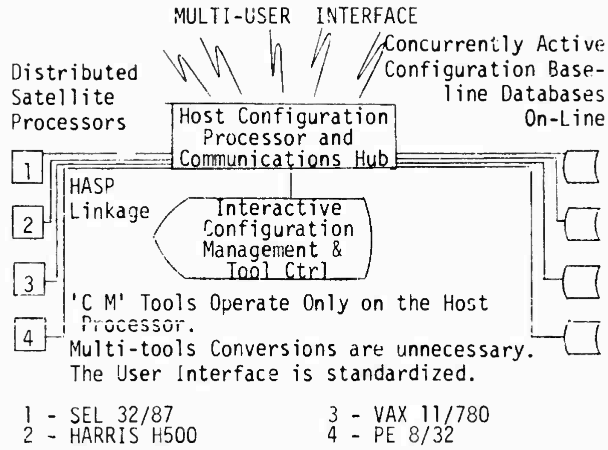


Figure 2. Distributed Configuration Management and Program Processing Network

The host configuration processor manages the distributed processing functions by dynamically creating procedure or job streams that will execute on the target satellite processor to accomplish a desired program processing function. These dynamic job streams are composed from job stream seed tables which define the functions and procedures to be executed. Configuration items by name and component which are managed within the automated configuration control database are swapped for identifiable labels found within the job stream seed table entries. Once the procedure or job stream composition is complete, communication procedures utilizing an emulation of HASP transfer the job stream file to the target processor for execution. With these automated procedures any target or device dependent computer can be supported within the configuration/program processing structure by simply constructing the proper job seed tables to accomplish the functions of program processing necessary for that computer.

Since the program processing satellite computer systems will not be performing software baseline management and storage, only a minimal operational architecture is required. Functional requirements include resources capable of executing a normal batch or procedure stream environment with remote HASP communications ability for bidirectional host configuration processor file transfers. Additional system software support capabilities may be needed for operating system and software tool development support at the satellite processor level.

Configurable Software Structure

All device software systems that are to be configured and managed by the automated configuration control procedures must be structured in a uniform manner so as to allow a generic set of automated software tools and procedures to operate by a common set of rules. MIL-STD 1644A is a military standard approved for use by the Naval Training Equipment Center and is available for use by all Departments and Agencies of the Department of Defense for trainer system software engineering requirements.(2) This standard, with its appendix A specifically, establishes the common set of rules which will enable the automated configuration control procedures to manage the many and various device software systems developed to this standard regardless of their origin, function, or embedded equipment. Appendix A defines the construction of the device system software so that incremental modifications may be readily performed and managed.(2) Additionally, the requirements for various data item deliveries are established which essentially make up the initial automated configuration control database load.

Figure 3 depicts the segmented task construction required by appendix A. Each program structure is divided or segmented into defined computer memory areas called windows. The beginning address of each window relative to the beginning of the entire program area is tracked within the configuration management database. The size of each window is selected so as to contain a logical module or a group of executable modules together with an initial spare memory area of fifty percent of the allocated window area.(2) This segmented structure allows each window area of the entire program to be independently modifiable via overlaying. This concept greatly enhances the incremental modification efforts by permitting the processing, i.e., link editing, transmitting (RJE), etc., of only that part of the program which is effected by the increment change. Also, the modification risk factor is lessened by the need for only handling that section of the program which is to be modified vice the usual need for handling the entire program for each change implementation. Once the configuration control database is loaded with the necessary data relative to a configured software baseline, construction of the entire program or any of its defined window areas as overlays can be accomplished by the automated configuration program processing system.

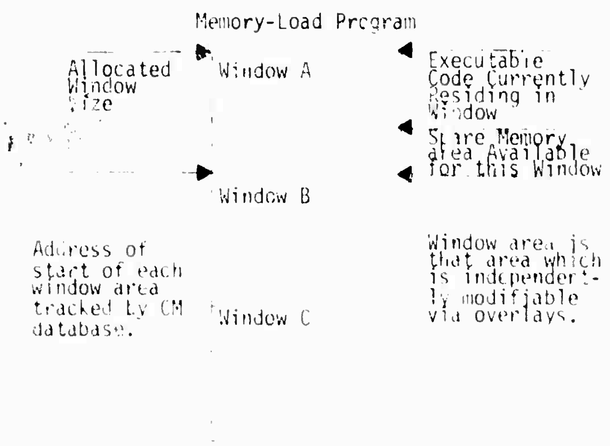


Figure 3. Window Segmented Task Structure

Operational Procedures

An effective modification and configuration management function requires a defined operational procedure and strict adherence to that procedure. This paper addresses an automated configuration management environment whose implementation none the less requires such an operational procedure. The SSF procedures described herein for automated configuration management are implemented in a circular fashion such that the modification/configuration management procedural flow terminates at the step where initial authorization for change implementation originates.

A software baseline modification process begins when device modification management authorizes the implementation of a device modification which impacts the software baseline. The cognizant software support activity performs a preliminary analysis to determine the software components effected by name. The SSF configuration management group is requested to begin configuration control of the modification implementation. Configuration management identifies the currently configured revision of the modules identified and reports as to their availability for modification. If a change is currently being implemented to any of the identified modules then the new modification to that module(s) must either be deferred or forwarded to the individual or group who has current cognizance for modification. If the modules are available then configuration management locks the modules to the requesting cognizant individual or group so as to prevent uncoordinated parallel modification efforts. A new revision level for the modified module is also assigned at this time. The cognizant software support activity performs modification design, source module change implementation, and the preliminary documentation updates. Next, a software design review is held to ensure good software design practices are used, to review documentation updates and test procedures, to ensure assigned configuration data items are correct and to ensure that the software change fully addresses the original change request. If the results of the software design review prove to be unsatisfactory then the software support activity continues with the implementation process until a successful design review result is attained. After a successful design review, the SSF configuration management group accepts the new module(s) produced from the previous baselined version into the configured software baseline account. Once configuration control has possession of the new software component, the automated configuration management system is utilized to produce a device loadable software component, i.e., an overlay, ready for device level testing. Arrangements are made by the software support activity with the custodian of the particular training device which is used as the test bed for modification software tests. Before the newly created modification software is released from SSF configuration control a pre-checkout status update is made to the automated configuration control database. This status entry, described in more detail later, indicates that the configured modification software has been released for device level testing but is not part of the current executable baseline. The modification software which is in overlay module form is ready for transfer to the device test site either via remote job entry (RJE) terminal reception or magnetic tape and the U.S. Postal Service. Additionally, detailed test procedures are provided with the software release under test. At this point either a field engineering representative (FER) of NTEC or an on-site member(s) of the cognizant software support activity tests the modification software by overlaying the current executable software on the training device in a test environment. If the operational test fails the configuration management group is notified and the configuration control database is updated to show that the test modification software is rejected in which case the modification work effort would be returned to the cognizant individual or activity. When a successful test is performed the modification software is qualified for release as an official Training Equipment Change Directive (TECD). The TECD will be supplied by device modification management to the applicable device sites as a kit containing the pre-tested modification software, installation and test procedures, and all applicable documentation updates. Once the device site support personnel have installed and tested the newly released software, NTEC is notified via a Record of Completion form supplied with the kit. The SSF configuration management group is notified and again the configuration control database is updated to show that now the modification software is approved for training and is currently configured within the executable baseline. All source baseline components which were previously locked for change implementation are automatically unlocked at the approval status update. Modification management is notified of the baseline update and the modification/configuration control operational cycle for that software change is complete.

Several software modifications may be in various stages of this cycle simultaneously. Also, more than one software support activity may be performing change implementations to the same or various other device software baselines. In any event, the same procedures and the same management is being performed for all active modification efforts.

Software Baseline Visibility

Visibility of the ever changing state of a configured software baseline significantly aids the baseline software management task. If the status of a baseline is obscure or difficult to assess no one benefits; not the software support activities and especially not device modification management. The automated configuration management procedures are designed to allow the display of the state of any configured baseline on demand. The configuration history/audit trail capabilities are implemented via a parent/sibling approach with eight levels of status for the various life-cycle stages a configuration component may traverse. Each occurrence of a new status condition is recorded within the configuration management database along with the date of the occurrence. All previous status/date entries remain available within the database and are recorded in chronological order of occurrence. The parent/sibling relationship of the baseline components is maintained y a chain key linkage. Each component database entry as it is created by a baseline modification effort is stamped with the database key of the parent component from which it was produced. In turn, the parent component database entry heads a chain key linkage which points to its siblings in the sequence they were created. As each new sibling is identified its key is placed at the bottom of its parent's sibling chain.

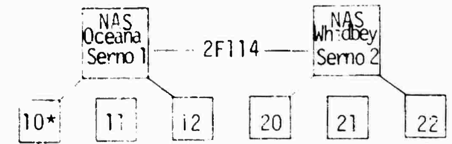
The combination of interrelationships among the parent/sibling chain and the various life-cycle status entries for each modularized configuration component yields a capability for on-demand configuration status displays and reports. Figure 4 is an example of a software modification status display produced by the automated configuration management system. The left-hand field of this display identifies by name and database key the structured window sequence of a single segmented task or program load. The configuration database entries whose keys are referenced here contain the actual modular construction of each window. The next field labeled "Approved" represents modification software or overlays that have been developed, applied, and approved for execution in the training environment and are part of current baseline for this task. These "approved" overlays are executing in place of their "installed" counterparts. The "In Check-Out" field identifies modification software that has been released by the configuration management group for device level testing. This software now physically resides on the test device for testing only. The last field identifies modification software that is ready for testing against this task but has as yet to be transferred to the device test site. Additional display capabilities show the current and previous baseline modification activities to any modular level. Any previous point in the baseline life-cycle history can be inquired upon for configuration content and modifica-

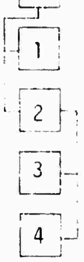
TASK MODIFICATION STATUS

TIME-> 29APR82 08:14:32 TASK-> TKAFOP10.TC0 MATRIX-> 10 CFG FRZ-> 12/15/80

WND NAME	INSTALLED	APPROVED	IN CHECK-OUT	UNTESTED
AROOT1	WC0 C060			
AROOT2	WC0 C253			
M1EXEC	VCA C90[illegible]			VCC C017 04/19/82
MMCRTA	VC2 C006			VC3 C010 04/06/82
MMIOA	VC1 C154			
MMADCA	VCP C228		VCR C267 12/14/81	
MMAERO	VCF C239	VCK C252 12/30/81		
MMAFC	VCU C236	VCV C007 08/27/81		
MMAPC	VCB C219	VCF C268 02/17/82		
MMAWCL	VCV C237	VC4 C266 02/17/82		
MMEOM	VCK C188			
MMFIRE	VC2 C178			
MMICE	VC3 C177			
MMMOI	VCD C152		VCG C157 02/19/82	
MMPFC	VCP C216	VCR C243 08/27/81		
MMSFC	VCI C214			
MMSURF	VCQ C240			
MMTOL	VC3 C234			
MMWING	VC3 C179			

Figure 4. Software Modification Status Display





*Configuration Matrix, 14 Task Conf.
1 - Conf. List Window Key & Sequence, Task 1.
2 - Configuration List, Task H.
3 - Conf. History Data Entry (Overlay List), Keyed Entry 1000. Source Data/Address
4 - Keyed Entry 1046.

- Each Matrix reflects the configuration of a task set release for a configuration year.
  Task References
  Task Map Names
  Task File Names
  Task Configuration List
- Each Task Configuration List contains the window/overlay keys and their sequence which comprise the associated task image.
  OCN (Overlay Control Number)

Figure 5. Tri-Level Configuration Database Structure

1000	1160	1211	1023	1128	1214	1112
1241	1221	1012	1039	1126	1073	1165
1042	1036	1226	1202	1122	1200	1056
1043	1216	1199	1220	1031	1225	1059
						1046

```
CONFIGURATION LIST    C  F  T  I  O  P  1  0
           Tactics Ind ---'
         Operate Mode -------------'
             Matrix 10 ---------------------'
        OCN Structure:        X
               Task Ref ------'       YYY
           Number Field -----------------'
```

This OCN sequence represents the construct of TASK TKTIOP10.T10 (TI6.TSK).

These OCN's are keyed to window/overlay contents for this particular task configured by Matrix 10.

These OCN's are 'INSTALLED' (IN) for Matrix 10.

Figure 6. Configuration List Dataset

tion status. At any point in time the current executing baseline is merely a request away with the SSF automated configuration management system.

Automated Software Configuration Management Tool

The software configuration management system revolves about a single configuration control tool. This software tool performs the configuration and program processing management functions for any number of training device baselines. Configuration management provided by this tool for the various supported software baselines is implemented with a three level database structure shown by figure 5. The outer level consists of a matrix file which relates a physical device by serial number to a baseline configuration level. A series of matrices each representing a configuration year will proliferate throughout the life-cycle of the device. Each record entry within the matrix file defines a single task or load program. Multi-program software baselines have as many matrix record entries as the number of separate tasks. Each entry references the task name, task load map, and task configuration list database key. This database key is the linkage from the outer data structure to the second level. The configuration list contains a sequence of third level data structure keys as shown by figure 6. Each of these third level keys point to a configuration history dataset entry (figure 7) which reference the actual modular constructs for every task window segment. The configuration list, therefore, relates the specific windows and window sequence which comprise the task associated with the list found in the matrix entry for that task reference. A status entry dataset which is at the same structural level as the history dataset contains the accumulated, chronologically ordered status entries associated with the life-cycle of each window/overlay component represented within the configuration history dataset. Figure 8 shows the eight possible status entries which a component may acquire.

An active software baseline is continuously evolving. The automated configuration processing tool described here maintains the configuration version base on a yearly cycle. Each yearly cycle, the configuration year, is referenced by a separate matrix. The configuration cycle begins with a configuration release which provides a new set of load programs and all base software (i.e., data, procedures, utilities, etc.) to each supported device as the installed software configuration base. During this year software modifications are implemented and approved as overlays to the installed base. Therefore, current executable configuration at any given point in time is the installed base plus any approved overlays. At approximately one month prior to completion of the current configuration year, the tool invokes a pre-freeze condition where new modification software releases are prohibited to allow a full testing period for current modification software approved for training on the device. Next, the tool performs configuration freeze which constructs new configuration lists (figure 9) from the combination of currently installed and approved window/overlays. New matrices are produced which reference the newly created lists and the new task names that will be produced from these new lists. When the freeze process is completed a new installed software configuration base is ready for release. The next configuration year is beginning and the modification process begins anew.

```
1000  AROOT1.W10   12/15/80  NTEC SSF  ENDC    ENDC
      02 ROOTEXEC  C70  B70                000200  000100
                             ENDPART               000216
1241  AROOT2.W10   12/15/80  NTEC SSF  ENDC    ENDC
      02 ASIN      .F70  B70               000800  000300
      02 RN        .F70  B70
      02 SYN       .F70  B70
      02 TAN       .F70  B70
      02 INTERP    .F70  B70
                             ENDPART               000A2!
1042  MIEXEC.VIA   02/19/80  NTEC SSF  ENDC    ENDC
      02 MIEXEC    .M71  B71               0004    000B00
      02 EXEC      .FYA  B1A                       000B50
      02 EXECOVLY.C71  B71                         00335
      02 EXECSHID.C7   B7                          0037
      02 ADTIME                                    0041
      02 IOMOD     .C7   B7                        00451
      EXECEND                ENDPART               00474
```

Figure 7. Configuration History Dataset

Window/Overlay Life Cycle Status

Status Entry:	Matrix ID +	Status +	Date
	10	PN	YRMODA
	10	UT	"
	10	CK	"
	20	CK	"
	10	AP	"
	20	AP	"

Typical Status Sequence for a Single OCN:

PN->UT->CK->AP->IN (Matrix + 1)->RP (Matrix + 2)
↘RJ ↘RJ ↘RJ ↘RM

PN - Creation Pending	IN - Installed (Task Image)
UT - Untested	
CK - Check-Out	RP - Replaced
AP - Approved (cemented)	RM - Removed (without replacement)
RJ - Rejected	

Figure 8. Window/Overlay Status Structure

The software tool providing this management capability is table driven and automated to the extent of removing as many human interactions as possible. This results in reduced human induced errors and reduced operator requirements for trainer software configuration management. The tool is initiated by specifying a device identification file which contains the device name and serial number, the database descriptor module name which identifies the configuration database for this device and the matrix identifier of the current configuration installed base. Also, a command file or input device is specified from which the automated tool will receive commands and sub-directives. These commands direct the tool to perform the various functions necessary to perform configuration and program processing management. However, once the functions are specified their execution is completely automatic. This automated tool allows maximum flexibility for the construction, maintenance, and software configuration trackability of one or any number of training device baseline versions and/or revision levels. By simply maintaining the device identification tables any trainer combination or multiple simultaneous combinations are possible and manageable.

MATRIX 10 CFAFOP10 (TKAFOP10.TCO)			MATRIX 11 CFAFOP11 (TKAFOP11.TCO)	
Installed	Approved		Installed	
C000			C000	
C253			C253	
C005			C005	
C006			C006	
C154			C154	
C228			C228	
C239	C252		C252	Modification
C236	C007	Config	C007	process con-
C219	C268	- -	C268	tinues from
C237	C266	Freeze	C266	here.
C183			C188	
C178			C178	
C177			C177	
C152			C152	
C216	C243		C243	
C214			C214	
C240			C240	
C234			C234	
C179			C179	

Figure 9. Task Configuration Freeze

Software Development Environment

The SSF service environments discussed herein have only addressed the modification of existing software baselines. A software baseline as used by the automated configuration management system must be established prior to modification support. If the initial baseline was actually developed using this system, then transition from development to support would become completely transparent as the baseline would already exist at completion of development. Baseline control and management would begin at the very onset of development. Just as importantly, the same visibility available during the maintenance phase of the software life-cycle would also be available during the development phase.

The development activity would begin with task or program function definition and then proceed to the modular and structural definition phases. At this point MIL-STD 1644A requirements begin to effect the establishment phase of the developing baseline and it is at this point when the automated configuration management system could be implemented as an efficient and effective baseline management procedure for the duration of the software life-cycle. Tool implementation would require an initial configuration matrix file load. The configuration history dataset would be automatically loaded as the window constructs are identified and processed. From a planned and engineered software system base design a configured software baseline would arise.

SUMMARY

The NTEC Software Support Facility has evolved into a concentrated central software support resource with which any modification or development activity can effectively implement software baseline changes while remaining within the guidelines of a strong configuration management. The automated configuration management system at the SSF provides software baseline protection and control, ease of baseline maintenance, and full development/modification visibility during the support baseline life-cycle. This automated and centralized environment permits a common contact point, a common set of procedures, and a single, common management of all supported device baselines under SSF configuration management. MIL-STD 1644A is the primary requirement that provides a common set of rules enabling various established baselines from various origins to be managed by a single generic configuration processing system. Older device baselines that were not designed by the requirements of MIL-STD 1644A may require additional effort to modify their structure and to provide the necessary support data for the automated configuration management system.

The combined modification management and configuration management procedures of the NTEC SSF environment provide a well defined procedural base for software baseline change implementations. The strong software configuration philosophy maintained by the SSF configuration management group will help ensure that NTEC can meet the challenge presented by the increasing inventory of software intensive training equipment. Software life-cycle manageability and visibility will be greatly enhanced while the costs of these most desirable capabilities are reduced. The requirement of an effective, unified management and control system for the compliant software baseline, cradle to grave, has been identified and achieved.

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(2) MIL-STD 1644A (TD), 15 January 1982, "Military Standard Trainer System Software Engineering Requirements", FSC IPSC-N194.

ABOUT THE AUTHOR

Mark M. Hargrove is the trainer software baseline configuration manager for the Software Support Facility Branch of the Naval Training Equipment Center, Code N-401. He has been active in the various aspects of trainer software support since 1975. Previously, he was involved in trainer hardware system maintenance and modification support with FASOTRAGRUPAC, NAS Miramar, California.
Mr. Hargrove has been a principle figure in the establishment of the software configuration management procedures, systems, and support tools within the centralized Software Support Facility.

USING SOFTWARE DEVELOPMENT FACILITIES TO IMPROVE SOFTWARE QUALITY

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A major problem exists in the development of current state-of-the-art weapons system trainers in the quality of the software provided. Since the software for a given trainer is typically generated on the deliverable computer system for the trainer a wide variance in the tools available to support the design and development of the software exists from project to project.

The specification requirement of a high order language (FORTRAN) has led to the evolution of software development facilities at various simulator manufacturers. While these have immediate impact in reducing the cost of the software produced and aid in maintaining schedule on the ongoing programs, their most significant impact is that the software delivered using them is significantly improved.

The paper explains what was experienced when the SDF concept was applied to some current contracts.

1. INTRODUCTION

The computer programs (software) developed for current state-of-the-art weapon system trainers (simulators) have been typically generated on the deliverable computer system, and thus have been subject to wide variance in the available software design, development, test and configuration control support programs (tools) from project to project.

Varying levels of available tools have been considered normal, especially when assembler languages were used on varying brands of computation equipment. The introduction of high-order languages (HOL), predominantly FORTRAN, as a specification requirement has led to the evolution of Software Development Facilities (SDF). The SDF concept was developed with three major objectives:

a. Reduce the cost of the software produced

b. Maintain or accelerate schedule performance of on-going projects

c. Maintain precise configuration control and management

These objectives have been fully realized, and the SDF provides deliverable software of significantly improved quality.

The Link* SDF has been designed to provide configuration control and management (CC/M) in a user friendly working atmosphere. Systems Engineering and software development personnel use conveniently located interactive terminals during all phases (design, development, test, maintenance, etc.) of unclassified projects.

*A trademark of The Singer Company

The principal features of this interactive capability are:

- Prepare and edit source code
- Compile and/or assemble the edited source code
- Prepare and edit Math Model Test (MMT) inputs
- Create a Software Change Request (SCR) for source code modified at the SDF

2. SDF TOOLS

Three basic categories of tools exist in all SDFs (see Figure 1):

a. Tools supplied by computer and software vendors

b. Tools developed by the software manufacturer specifically for the SDF, normally via IR&D programs

c. Tools developed under contract as deliverable contract end items

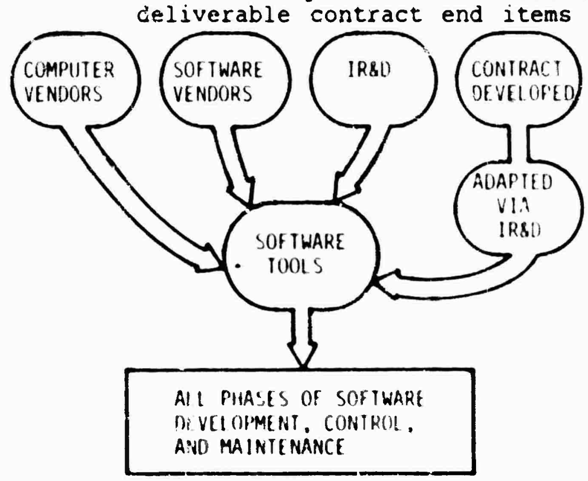

Figure 1
Software Development Facility Tools

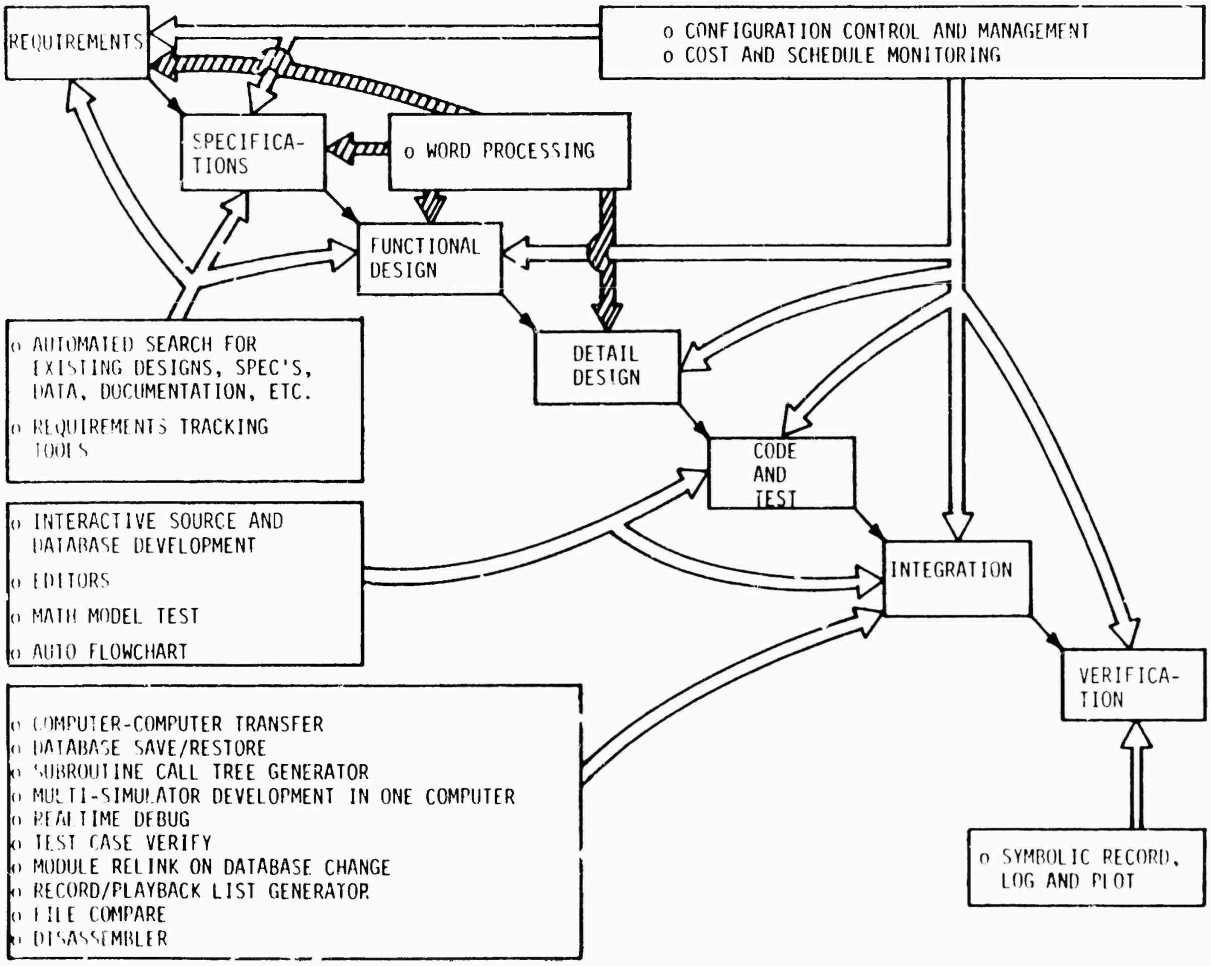

Figure 2 SDF Capabilities Used During Simulator Development

2.1 VENDOR SUPPLIED TOOLS

The Link* SDF is equipped with a large number of proprietary tools supplied by the computer vendor such as operating systems, data base management systems, terminal systems, compilers, assemblers, loaders, librarians, etc. The high-order languages (HOL's) supported include: FORTRAN, COBOL, BASIC, and PASCAL. In addition Link has purchased special purpose proprietary software for use during specific phases of a simulator's life cycle. Examples of this software include: a lens design package used by visual engineering during the proposal and conceptual design phases, a microcomputer cross assembler and emulator, sophisticated print and plot packages, a cost and schedule monitoring package providing critical path and other automated management capabilities and a comprehensive system providing full-field search and selected output of cited data within the Engineering Information System (EIS).

Figure 2 shows the traditional development cycle of a simulator through customer acceptance (verification). At each stage of this process, the SDF enhances our ability to quickly and accurately perform the indicated task.

2.2 LINK DEVELOPED TOOLS

Extensive systems and tools have been developed to control and enhance every access to the SDF. These capabilities may be best understood through an explanation of key features:

- <u>COMPILATION COMMANDS</u>

  Single commands to accomplish the compilation, library edit, and production of various optional types of output, as discussed. Examples: ASSEMBLE, FORTRAN.

- <u>MULTI-SIMULATOR SUPPORT PACKAGE</u>

  Software that interfaces to CC/M managed software. It basically allows copies to be made from CC/M disks, while prohibiting unauthorized changes. The copy can be used to develop the required version, along with the applicable database (Symbol Dictionary) entries applicable to the specific project.

- **OPERATOR COMMAND STURCTURE/ VENDOR UTILITY COMMANDS**

  Tools developed to utilize vendor software, formalizing the way is to be used by each operator. This is required to provide consistent operation.

- **EDITOR/FULL SCREEN EDITOR**

  Editors are used in developing software, test drivers, etc. These tools provide flexiblity, via English language commands, while protecting all fields used by CC/M software.

- **FILE COMPARISON**

  Allows automated generation of the CC/M required SCR by comparing configuration managed code to new code on a line by line basis. The printed SCR conforms with the specification required format.

- **SPECIAL UTILITIES**

  Single commands to accomplish repetitive functions (e.g., file copy, list, transfer, etc.). Also provides processors to inspect definitions of parameters and symbol edit.

- **HELP**

  Information capability, at the terminal, to aid users in proper SDF utilization.

- **MATH MODEL TEST (MMT)**

  A comprehensive software methodology that leads to consistent test and verification of design logic in a non-real-time mode of operation. Capable of exercising single modules, components, etc., up to an entire simulator load Capable of accepting commands in either th interactive or command file mode. Software Quality Assurance requirements (e.g., test coverage reports, regression testing, etc.) are incorporated.

- **PLOT PACKAGES**

  Allows offline software and MMT to interface with various output devices.

- **FILE TRANSFER**

  Allows multiple computers to transfer files, in either direction, via RS-232 channels. Error checking/verification is provided.

3. IMPACT OF THE SDF

Before the SDF was developed, many tasks were performed on the deliverable computation equipment in a serial manner during software development and test. Now these same tasks may be accomplished in parallel on the SDF. This factor alone allows more online time for those tasks which cannot be performed at the SDF such as hardware-software integration. Figure 3 shows the serial versus parallel work flow.

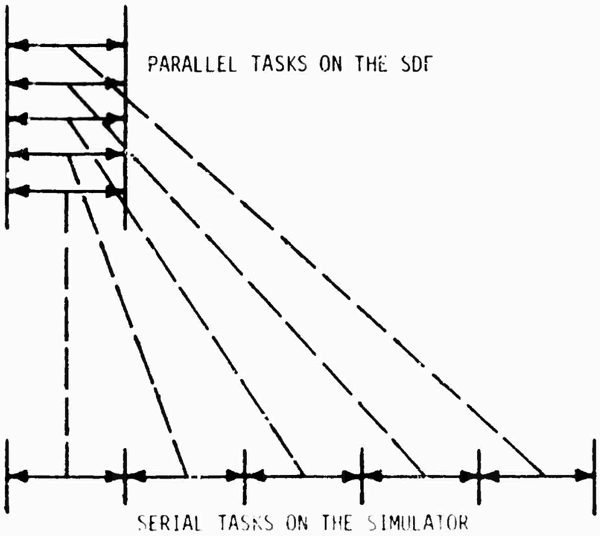

Figure 3 Serial Versus Parallel Work Flow

3.1 LOAD GENERATION

A simulator load may be defined as the complete set of executable software and data bases required to simulate the real world device, ready for insertion into the computer's memory system. Prior to the SDF, simulation loads were normally generated once a day. Because of the serial development, and limited available computer time for detailed testing, subtle problems existed with at least some of the newly incorporated software. Isolation and resolution of these problems reduced achievable progress in a given period of time. Furthermore, load generation and initial checkout, i.e., a cycling load, required an average of 2 to 3 hours. Figure 4 shows the process and results.

In the SDF environment simultaneous execution of tasks provides more time for each engineer to fully verify his module(s). Added testing, using MMT, yields software which is much more error free, thus reducing the load generation and checkout time to an average of 20 to 30 minutes.

Assuming one load per day, the use of a SDF provides an online savings of 1.67 to 2.5 hours per day, or from 51.8 to 77.5 hours per month (31 days).

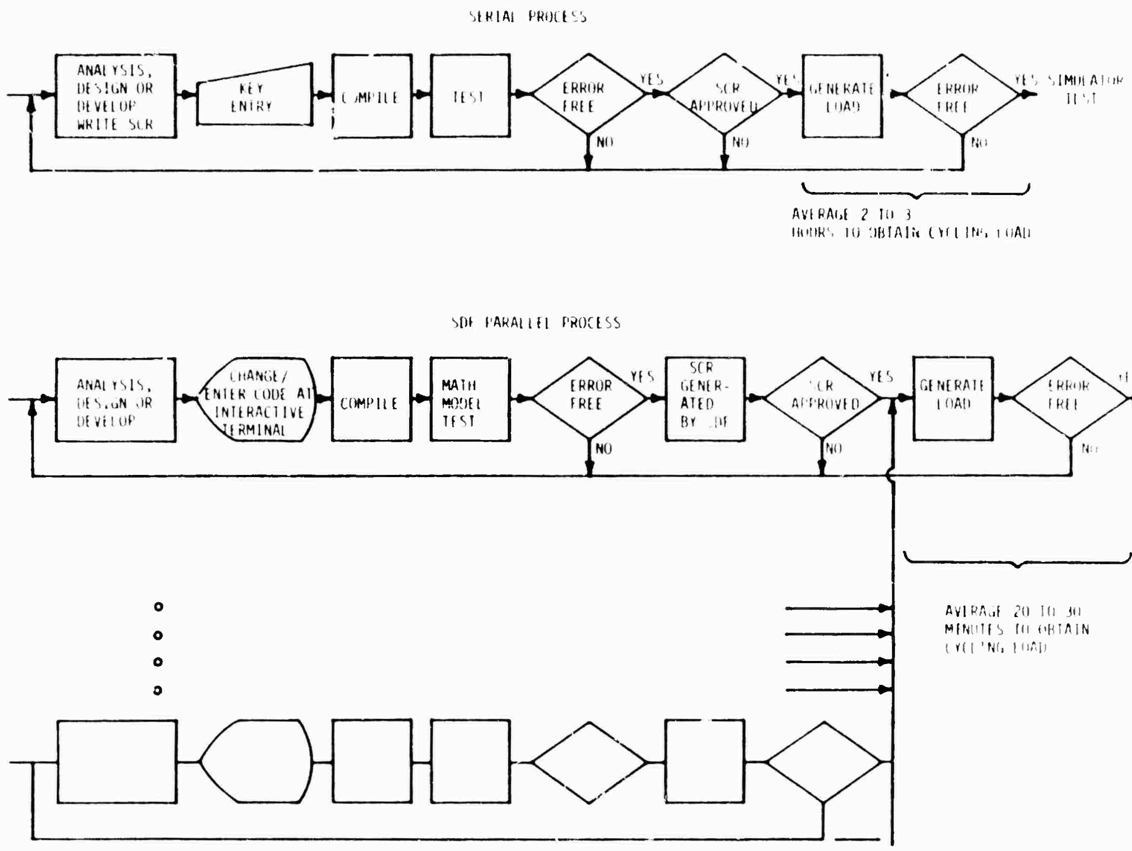

Figure 4 Comparison of Old and New Methodology On Load Generation Process

3.2 AIRCRAFT SYSTEMS

Aerodynamic and power plant (engine) simulation requires complex offline software to verify that the simulator design and implementation truly match the aircraft characteristics and performance as defined in the data available. The offline software also is used to develop usable test criteria in accordance with the specification. Before SDF, an offline computer complex was used to perform these functions. However, the ever-changing online computer vendors soon made it necessary to develop two identical sets of aerodynamic and engine modules; one in the language applicable to the online computer and the second in the language of the offline computer.

Use of the SDF allows significant savings, such as the following:

- Acutal simulation modules are used in the SDF.

  Savings: No duplicate modules written for different computers; no duplicate CC/M costs.

- Complex Test Drivers may be used across project boundaries.

  Savings: No duplicate modules or added CC/M; sophisticated drivers used on C-130, B-52 simulators.

- Math Model Test (MMT) verifies design, implementation, interfaces, modifications, etc.

  Saving: More effective than traditional online debug; shortens online test phase.

- Auto-Test Guide, an online test tools, is fully compatible with MMT, allowing identical checkout on the simulator and in the SDF.

  Savings: Reduced online regression testing associated with discrepancy clearance.

The SDF saved two weeks of online HSI time on the C-130 Program. The original HSI schedule provided three weeks for aero and engine integration, while the actual integration was completed in one week. Reason: More controlled development atmosphere, software quality controls, and in-depth testing on the SDF.

3.3 CONFIGURATION CONTROL AND MANAGEMENT

The SDF incorporates many features which assure that CC/M is correctly accomplished.

- o Fully controlled access to all levels of software.
- o Added controls limit controlled software updates.
- o Log of all users, the functions performed, date, time, computer resources utilized, etc.
- o Automated revision logging on target module and in CC/M database.
- o Automated SCR generation, log and reporting.

In addition to automated capabilities, manual intervention features have been incorporated into the SDF, and are used by CC/M personnel on projects such as the B-52 WST. Example of these functions, relative to incorporation of a B-52 WST change, are:

a. Determination of applicability, i.e., All B-52s, B-52G only, B-52H only, etc.

b. Determination if a basic (used simultaneously in more than one station) module.

c. Determination if the change must be retrofitted to previously delivered simulators.

d. Verification that all applicable documents have been updated and that copies are in the change package.

e. Verification that software quality requirements have been met.

When these actions are completed, the complete package is presented to the Software Change Control Board for approval or disapproval. Approved changes are logged into the CC/M system and then sent to the Software Controller(s) for incorporation into the load.

Historical data, current status, module effectivity listings, software trees and reports on all activities are available from the SDF upon request.

Cost savings (avoidance) has been estimated at $20,000 per month by using the SDF for CC/M. This figure represents our estimates of additional personnel required in lieu of the SDF for CC/M.

4. DEPS CAPABILITIES

Many current contracts include an offline computer complex designed to support the simulator at the customer's installation. The similarity of mission in the SDF and DEPS indicates a potential for transfer of SDF software to the DEPS.

5 CONCLUSIONS

Usefulness of the SDF has been proven at Link. A recent U.S. Air Force simulator contract had a program plan, developed prior to the SDF, which contained a six month Hardware-Software Integration (HSI) schedule. While the contract was in progress the SDF became operational and was fully used to control, develop and test software. The effect of the SDF is shown in Figure 5.

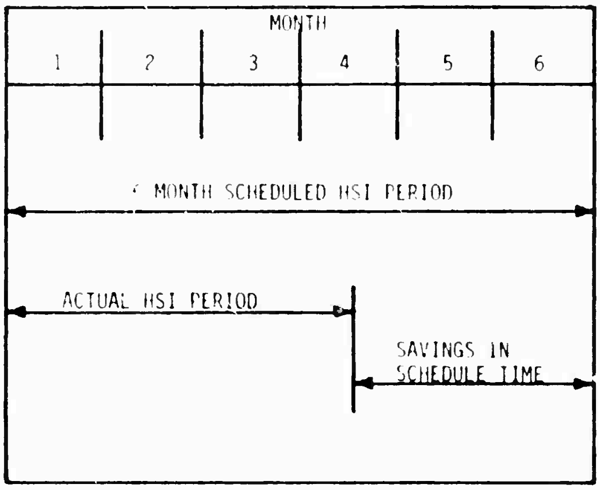

Figure 5 SDF Effect Upon Major Simulator

During the software test phase (pre-HSI) the SDF recorded 3400 hours of use. Since the types of testing being done on the SDF were identical to the testing normally done online as pre-HSI test, one may conclude that an hour on the SDF saved an hour on the simulator. Further, assuming that the simulator was available for test 16 hours per day and 31 days per month, the 3400 hours translates to 6 months of simulator time.

HSI on this simulator progressed unusually well with very few module interface problems. This resulted in the HSI phase being completed in about one-half of the time originally scheduled. Each simulator manufacturer and customer can calculate their estimated savings when the schedule is reduced by 2.8 months.

What will the future reveal? Certainly more complex and difficult requirements and specifications, especially in the areas of verification and validation. Will today's SDF and tools meet future needs? Not totally, but proven SDF philosophies, designs, procedures, tools, etc. will give the SDF owner a competitive edge.

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360 DEGREES VISUAL TARGET SIMULATION FOR OUTDOOR FIELD TRAINING

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Joseph A. LaRussa
V.P. Advanced Engineering
Farrand Optical Co., Inc.
Valhalla, New York

ABSTRACT

A dynamic target simulation system design is described which uses the real world as background scene. An instructor driven threat scenario is projected on a beamsplitter combiner. A collimating lens system makes the target appear as part of the real world viewed through the beamsplitter. High resolution target signatures are obtained by shrinking 525 raster lines down to a minimum area. A 360 degree visual hemisphere is provided by synchronization of gunner's line of sight and location of the simulated target in space. The gunner's line of sight is fed to the microcomputer control via an electromagnetic sensor. An occultation system is provided for the target to disappear as it moves behind trees or mountains. Scoring capability is also provided, and events may be stored and played back for training/review at a later date. Since the system is portable and relatively inexpensive, it will readily lend itself as a visual target simulator for outdoor field training in antiarmor (e.g., DRAGON and TOW) and air defense weapons (e.g., STINGER and CHAPARRAL).

INTRODUCTION

Field training in target acquisition currently requires provision of live aircraft/tanks/armored vehicles or live targets to represent threat scenarios. Considering aircraft/target availability, rising cost of fuel, restricted flight-paths/range-areas, high cost of live targets and their limited performance envelopes, it is not surprising that most gunner training is currently performed indoors using projection systems and domes (1) or simply a low cost arcade game in an air conditioned classroom (2).

Obviously we cannot expect an indoor trained gunner with little or no training in adverse field conditions to confidently engage a high-value threat on the first attempt in an actual battlefield. To provide maximum operational proficiency and confidence in firing the actual weapon in adverse environmental conditions, field training is an absolute necessity (3).

The purpose of this paper is to present a cost effective visual system to simulate realistic moving targets for outdoor gunner training.

DESIGN CRITERIA

The proposed concept was formulated based on the following criteria and guidelines recently outlined by several high ranking officers of military training commands (4).

Commonality of Device

The system is designed so that it can be used in conjunction with several surface-to-surface or surface-to-air weapons. Examples are STINGER, CHAPARRAL, VULCAN, DIVAD, DRAGON, TOW, REDEYE and almost any other weapon system that requires visual acquisition and tracking of moving targets.

Using Actual Weapons for Training

The rising cost of simulation, and therefore the need to trade-off simulators for the weapon system itself, has resulted in emerging preference to use, whenever possible, the actual weapon system with dummy rounds as a training device. The proposed visual simulator is designed so that it can be hooked up to the actual weapons or existing outdoor weapon simulators. This allows maximum transfer of training to the real weapons at considerably reduced cost.

Provisions for Crew Training

The visual simulator is designed such that the system parameters may be viewed/varied not only by the gunner, but by the crew in which the gunner is a member. In this manner, the system allows simulation of crew interaction, particularly among smaller units.

Dollar Leverage

Training exercises using targets are very costly and are also limited by the size of range areas, target/aircraft availability, restricted flight paths and friendliness of our own aircrafts. The cost factor is especially important because long and frequent repetition of exercise is required to develop good operator proficiency.

The proposed visual simulator presents a low cost alternative to simulation dome structures and their projection systems. Utilizing the real world as background scene, there is no need to use expensive computer image generators (CIG) to create realistic visual scene details. High resolution targets are generated through utilization of relatively low cost microprocessors, video discs and optical components.

Consequently, it is believed that the proposed device offers a real dollar leverage pay off to the user community.

SYSTEM DESCRIPTION

System Overview

Figure 1 shows a schematic diagram of the system. Prerecorded moving target scenarios are generated by mircroprocessor-driven video discs. A position sensor is used to provide gun-pointing direction or the gunner's line of sight in pitch, roll and yaw. This information is synchronized with corresponding frames on video disc to generate appropriate visual cues. Frame identification numbers and Society of Motion

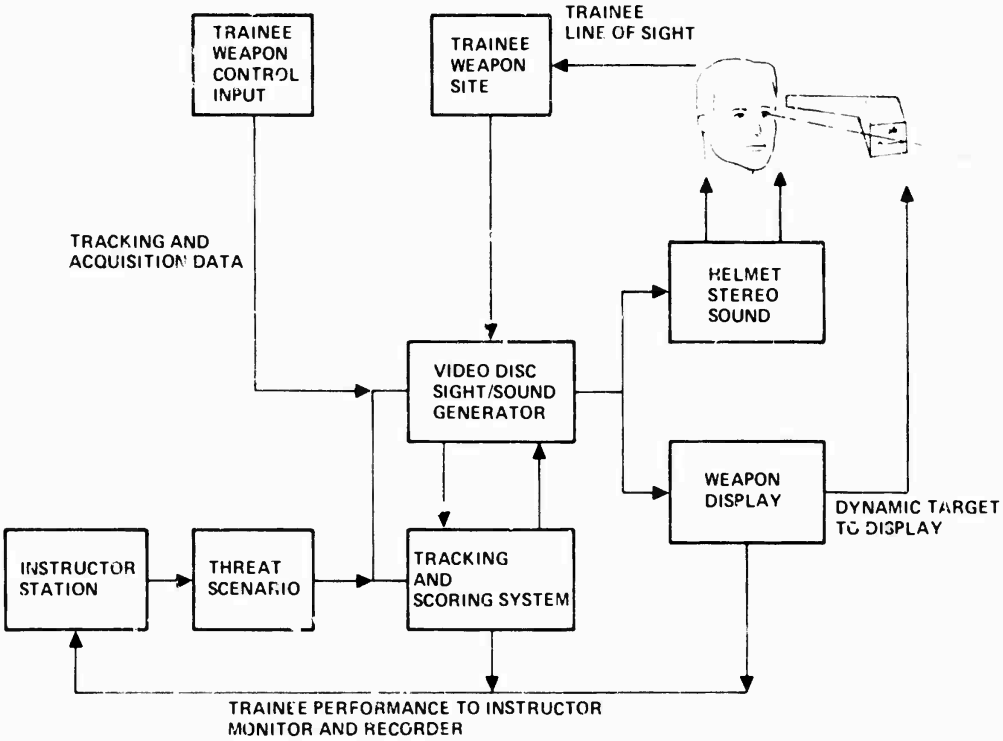

Figure 1. System Schematic

Picture and Television Engineers (SMPTE) codes are used not only for proper sequencing of frames but to also contain target information such as range, direction, speed and its center of gravity (CG) within each frame. The microprocessor uses the gunner interface inputs, his aim point and the target information to generate tracking and scoring data for evaluation of gunner performance.

To better illustrate the system, we describe its application to STINGER training. STINGER is an air defense system capable of being shoulder fired and destroying high value targets ranging from hovering helicopters to high speed maneuvering aircraft (5). Presently, live fire training for STINGER gunners is accomplished using the Stinger Launch Simulator (STLS) against live aircraft as shown in Figure 2. The training tasks and decisions are shown in Figure 3. The initial tasks of scanning the sky and detecting the target is generally achieved by an assistant gunner who uses both eyes and points to the target as shown in Figure 4. The gunner then shoulders the weapon/simulator and performs the remaining tasks using monocular vision.

An artist's concept of the proposed visual system applied to outdoor Stinger Training is shown in Figure 5. Note that the gunner and his assistant share the hardware/software used to measure the line of sight coordinates and to generate and synchronize their corresponding visual cues.

Off-Line Moving Target Scene Generation

Simulation of moving targets can be recorded remotely using computer graphics/animation techniques or by utilizing miniature models of potential enemy aircrafts against a plain back drop to generate realistic target maneuvers. Using either method, a video tape of several threat scenarios is obtained. For each video frame, the coordinates of the target in space, its range, speed and the coordinates of the picture element (pixel) representing the CG of the target or its IR plume within the frame are determined. Using either the SMPTE or Manchester Codes, the location, range and the CG information is stored within each frame during tape-to-disc conversion. The purpose of storing this information is to reduce software overhead involved in scanning each frame when gunner's line of sight is sensed to position the appropriate frame against the real world. The information is also used for real time generation of gunner's tracking data.

Several off-the-shelf industrial video disc units are described in Reference 6. Most units provide 54,000 frames allowing up to 30 minutes recording of threat scenarios. The instructor may choose any prerecorded scenario and make it visible to the trainee or observer through the Target Display System. To help the trainee find the target, an audio simulator generates the target noise signature from the direction of the target.

Figure 2. Outdoor Stinger Training Against Live Aircraft

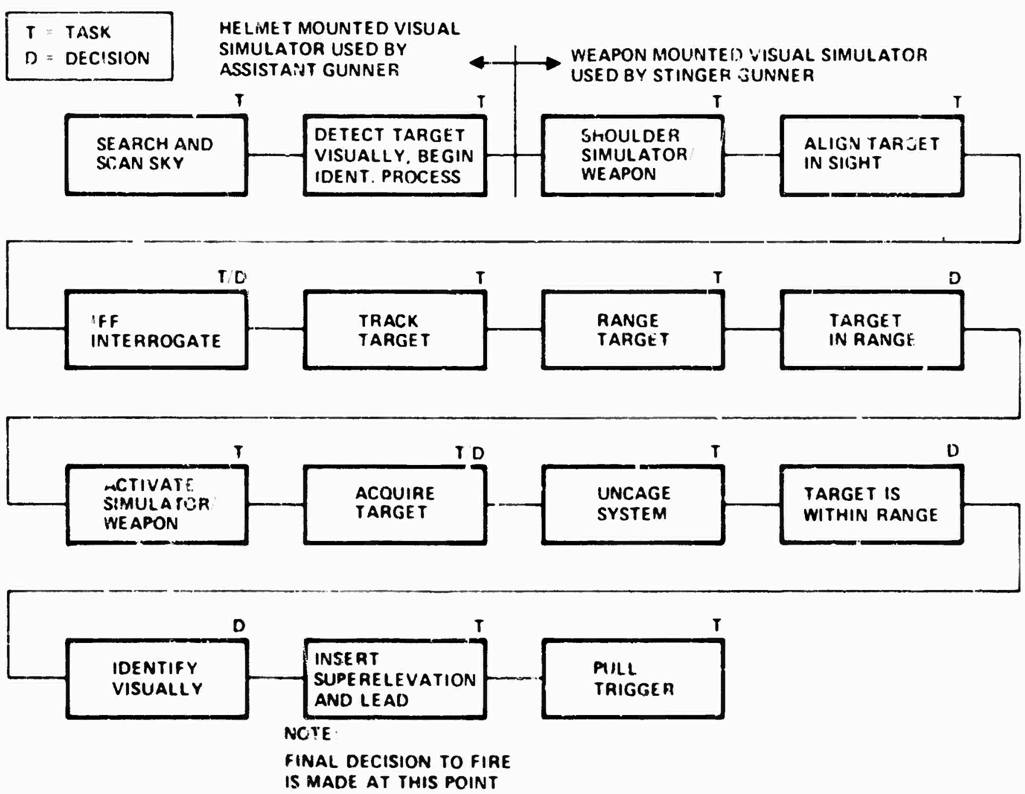

Figure 3. Stinger Training Tasks and Decisions

Figure 4. Crew Interaction of Stinger Trainee and Assistant Gunner

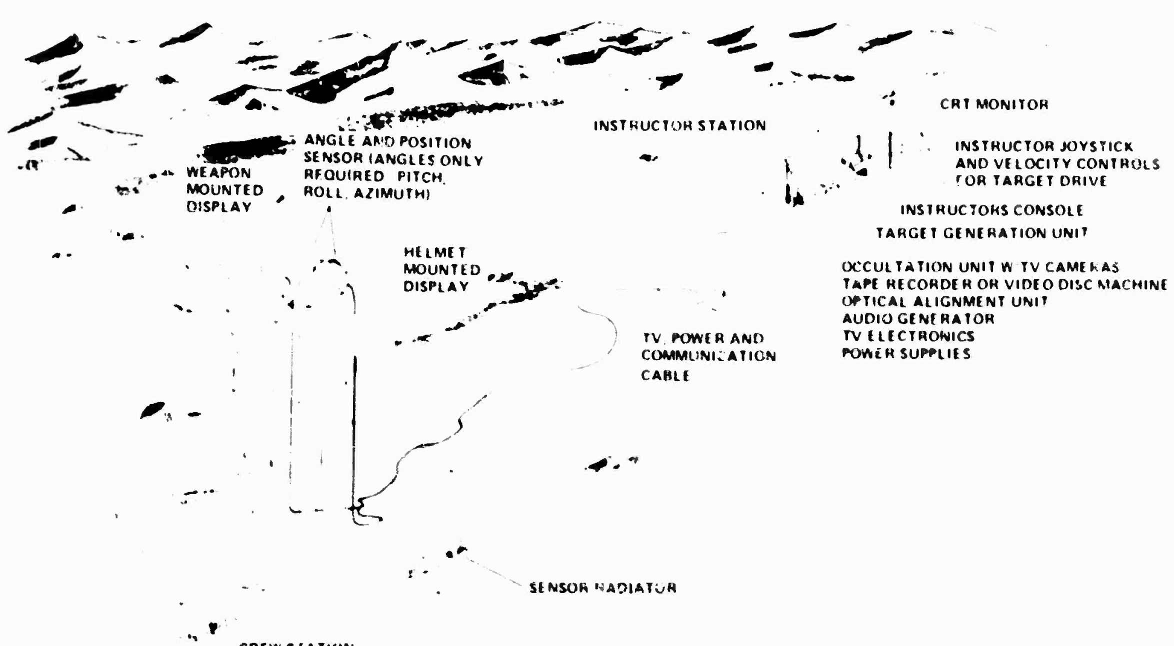

Figure 5. The Visual Simulation Concept Applied to Outdoor Stinger Training

Target Display System

The Target Display System can be either monocular or binocular depending on the weapon system and the training requirements established during front-end analysis. A helmet mounted binocular system would be appropriate for Chaparral training whereas a weapon mounted monocular system may be used for TOW training. As for Stinger, both types can be used — a weapon mounted display (WMD) for the gunner, and a helmet mounted display (HMD) for the assistant gunner as shown in Figure 5. HMD and WMD have the same basic design. The former uses 2 CRTs whereas the latter uses only one. The microcomputer controlled input from video disc is fed to a high resolution, high brightness miniature CRT such as Ferranti's Microspot 02D/117 weighing less than 3.2 oz with volume below 4 cubic inches. A lightweight optical system of mirrors, collimating lens and beamsplitter is used to project the moving target to infinity so that it appears as part of the real world.

A schematic of a helmet mounted target display system is shown in Figure 6. The parameters that should be considered include size, weight, exit pupil, eye relief, field of view (FOV), distortion, beamsplitter reflectivity/transmissivity, image to ghost ratio and several others. These parameters and their values for several off-the-shelf HMD's are described in Reference 7.

Since the beamsplitter can have a neutral density coating with at least 75% transmission (=25% reflectivity), the brightness reduction of the external scene is hardly noticeable. Assuming the optical elements used to project the CRT image pass about 85% of the light, the effective transmission for the moving target is therefore 21% (=.85 x .25). Accordingly a 5000 ft lambert brightness target will appear at 5000 x .21 = 1050 ft. lambert to the eye. This provides sufficient contrast to allow visibility against a 10,000 lambert sky background.

The HMD shown in Figure 6 has the capability of achieving very high resolution over the full sphere of vision because the generated moving target fills only the instantaneous FOV of the observer. The instantaneous FOV is 100° wide by 60° high. Each eye is furnished with a 60° circular by 60° vertical FOV. The overlap field between the eyes is 20°. As for the WMD, the gunner's FOV is limited only by the structure of the weapon sight as shown in Figure 7.

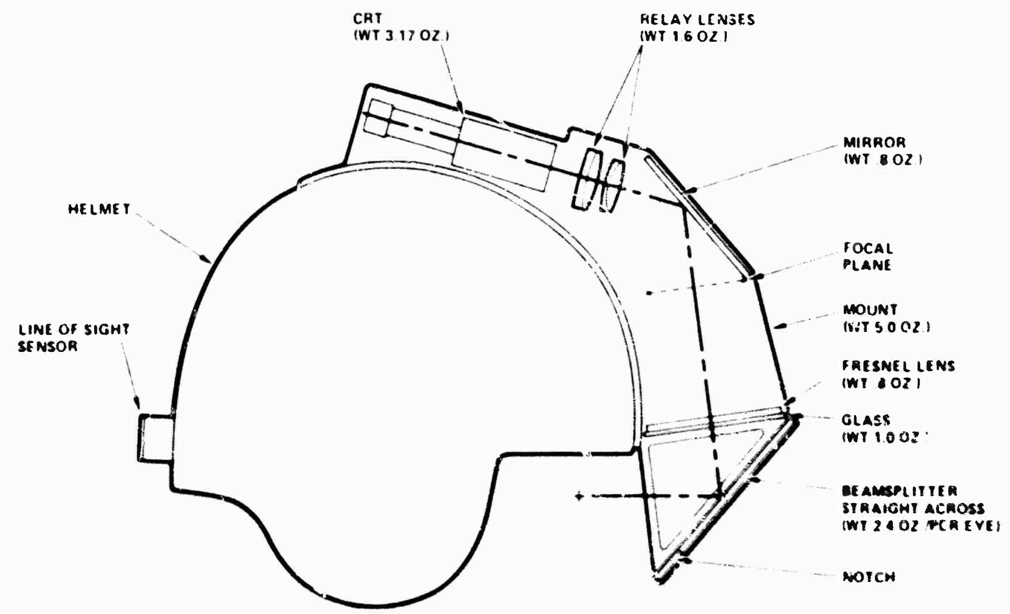

Figure 6. Helmet Mounted Target Display System

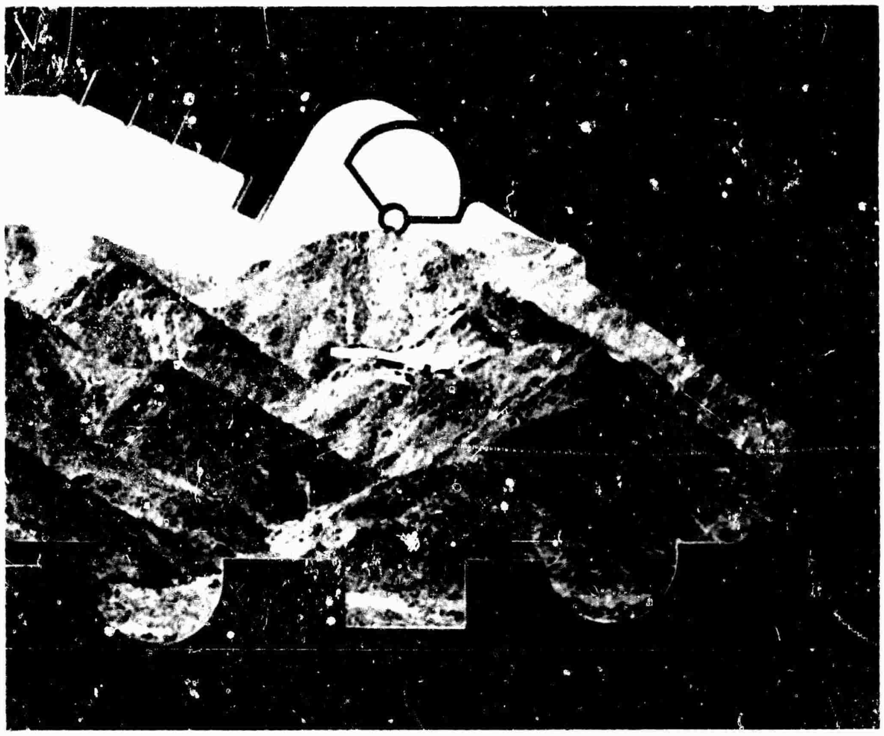

Figure 7. Stinger Gunner's View Through the Weapon Sight

Target Occultation

Figure 8 illustrates the observer's view through his HMD beamsplitter. Note that the far target is occulted by a mountain. This dynamic concealment is accomplished by the occultation unit shown in Figure 9. The three 35mm films are driven together by the motor-tach in response to the observers azimuth rotation of his head or weapon. In this manner the film silhouettes are always aligned to the real world background. The films are made in the laboratory to provide only black and white information from panoramic photographs taken from the trainees station. This assures exact correspondence between silhouettes and background ridges separating sky from terrain. A maximum of three ridges will be used since it is felt that this will provide a sufficient number of valleys within which enemy aircraft can approach with concealment. The television camera may be made to "see" any of the three ridges by merely indexing the film drive system up or down. This ridge data permits the occultation of the aircraft by terrain features so that flight behind mountains and reappearance is easily accomplished in accordance with the principles outlined in Reference 8.

In operation the azimuth rotation of the observer's helmet/weapon rotates the film unit so that the TV camera always "looks" at the same real world silhouette as the observer is viewing. When he turns to the aircraft location he will see the aircraft within his field of view. This requires not only the correct azimuthal direction but also his elevation angle of view and his head roll angle to present the proper attitude through his sight. These angles are generated by a line of sight sensor.

Line of Sight Sensor

The threat scenario should be seen only when the observer looks in the direction of the moving target location. This requires a high precision sensing device that continually supplies the host microcomputer with elevation, roll and azimuth of the gunner's weapon and/or the observer's helmet (9). Such sensors are called Helmet Mounted Pick-offs (HMP). The parameters that should be considered include size, weight, accuracy, angular coverage, freedom of movement, slew rate, update rate and the cost effectiveness of the sensor. There are several off-the-shelf HMPs developed using mechanical, light emitting diodes, ultra-sonic or infrared-based sensing techniques.

A candidate HMP for the visual simulator is an electromagnetic system developed by Polhemus Navigation Sciences as shown in Figure 10. The principal of operation of this device is described in Reference 10. Feasibility experiments utilizing the Polhemus sensor in conjunction with HMD's, have been conducted by the Aerospace Medical Research Laboratory at Wright Patterson AFB and the Advanced Simulation Concepts Laboratory at NTEC (11). These experiments indicate that the magnetic sensor's attitude precision exceeds 0.025° and its throughput delay is around 10 milliseconds. The angle output is updated 60 times per second. Since the video stream runs at 30 frames per second, this allows over 16 milliseconds of microprocessing time between consecutive frames.

One advantage of the Polhemus device is that it can handle two sensors simultaneously. Applied to Stinger Training, this would generate line of sight information for both the gunner and his assistant, thus allowing simulation of crew interaction while sharing the same hardware/software configuration.

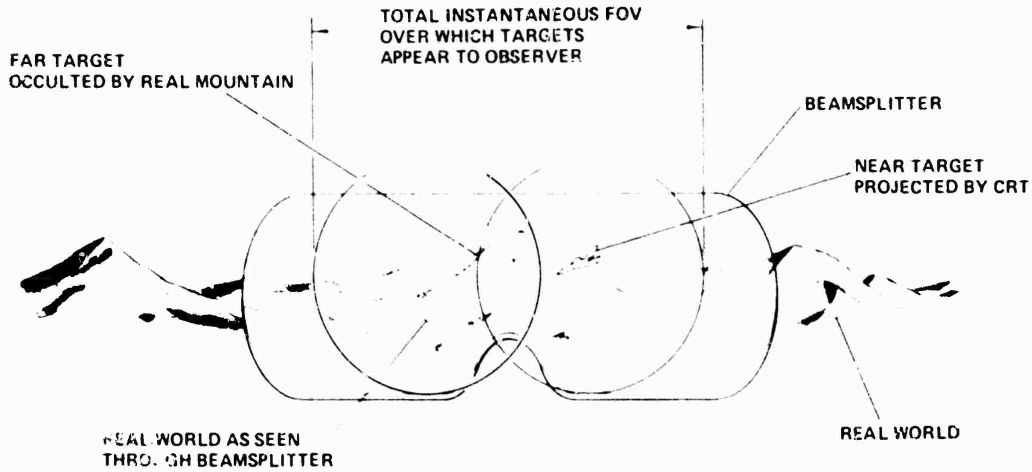

Figure 8. View Seen by Observer of Moving Target Superimposed on
Real World Scene with Occultation

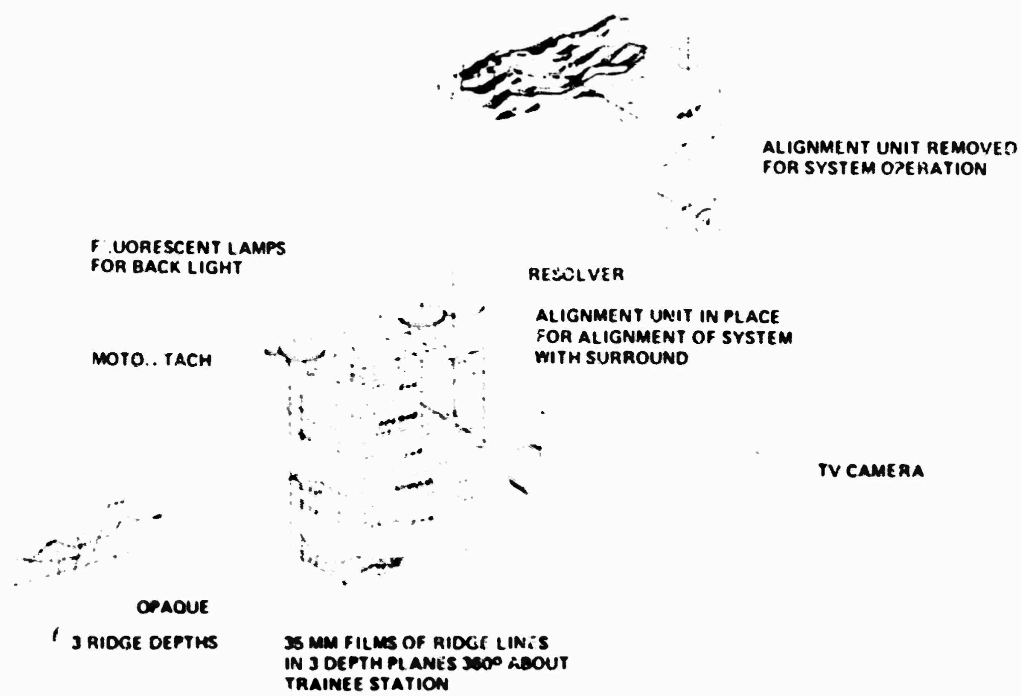

Figure 9. The Occultation Unit

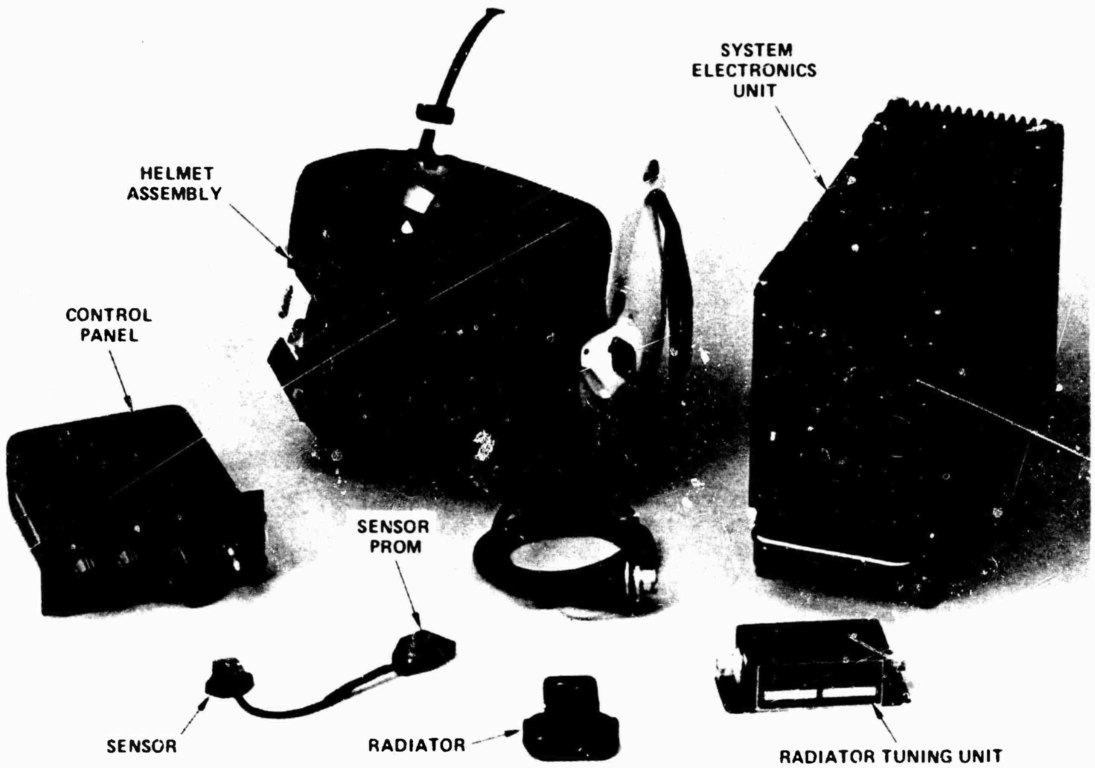

Figure 10. Major Components of an Electromagnetic Helmet-Mounted Pick-off

Microcomputer System and Software Design

The nucleus of the system consists of a 16-bit CPU, operating system ROMs and scratch pad RAMs. Four off-the-shelf microprocessor families have been evaluated. These are Digital Equipment Corporation, LSI 11/23, Motorola 68000, Intel 8086 and Zilog 8000. The 68000 family appears to be most suited for this application due to its short I/O interrupt kernel execution time (33 ms versus 114 ms for DEC's LSI 11/23), and its relatively fast bit set, reset test requiring least bytes of code.

To maintain commonality of the device across several weapon systems, the operating system contains firmware designed to perform generic control functions such as synchronization of HMP sensor updates and moving target image selection from video disc, tracking and scoring algorithms, and synchronization of audio and video signatures based on gunner's line of sight. Weapon dependent control functions such as gunner's interface data are stored in a ROM for a particular weapon system. The ROM is interchangeable from one weapon to another. In this manner, the bulk of system software is made independent of a particular weapon, thus providing the ability to optimally tailor the visual simulator to the requirements of a specific weapon system.

Scoring Capability

As part of the WMD module, a CCTV is located on the weapon and boresighted to the gunner's sight. As the gunner tracks, the instructor sees the target moving against the background on his CRT monitor. For Stinger, the gunner's direction of look, supplied by a weapon-mounted sensor, is indicated by a 15° (relative to the real world) circular reticle. His effort in tracking the target becomes obvious and his electrically sensed trigger pull freezes the circular reticle and the CRT scene. This permits scoring of his accuracy as well as acquisition time.

For wire-guided weapon systems such as TOW or DRAGON, the gunner's aiming error is calculated every 33 milliseconds using real time HMP input and the moving target's IR pixel coordinates from each video frame. The aiming error is then used by the host microcomputer to generate guidance error commands and to analyze gunner's performance.

CONCLUSION

The design concepts discussed in this paper represents an effort by the training device industry to be responsive to interservice training requirements. In terms of realism, the visual system described offers the 3-dimensional sights and sounds of the real world. Being microprocessor-based and using off-the-shelf equipment, the system is extremely cost effective. The commonality of hardware components and software architecture make the device applicable to several weapon systems.

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THE TREND TOWARDS AREA OF INTEREST IN VISUAL SIMULATION TECHNOLOGY

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ABSTRACT

The challenge of providing a cost and training effective wide field of view, high detail density visual environment to the trainee in a flight simulator is being answered by developments in both the generation and display of visual imagery. To overcome the inefficiency and cost of filling the large field of view using multiple television projectors giving butted images, various techniques are being developed for concentrating high image detail in an area of interest (AOI) which is usually of high resolution and set within a larger field of view of low resolution. This paper reviews the advantages and disadvantages of the various AOI techniques including an AOI that is tracked with a target, tracked with head attitude, and eye tracked. Particular reference is made to recent Navy, Air Force and Army developments.

INTRODUCTION

Simulation of the view seen by the pilot through the windows of a cockpit has been one of the most difficult problems in simulation technology. For takeoff and landing with fixed wing aircraft, computer generated imagery displayed on one or more cathode ray tubes, each fitted with infinity image optics, has reached a satisfactory stage of development and is now a very widely used technique. For air combat maneuvering (ACM), satisfactory results have been achieved on a few trainers over a period of more than two decades by projecting an image of a target aircraft onto the inside of a spherical screen surrounding the simulator cockpit. However, the simulation of a wide field of view of terrain in high detail as is needed in military simulation for low altitude flight, navigation, target acquisition, weapon delivery, threat avoidance and confined area maneuvering for both fixed wing aircraft and helicopters remains a difficult and expensive problem. It is the "last frontier"* in visual simulation.

The best currently available approach to providing the required high resolution, wide field of view (FOV) display is to divide the FOV between a number of butted displays surrounding the pilot. Each display requires its own channel of computer image generation (CIG). The number of displays and CIG channels required depends on the total displayed FOV required, the resolution required and the number of picture elements (pixels) that can be displayed in each window. Television systems with 1023 scan lines are becoming more common (as compared with the broadcast system standard of 525 lines) so that approximately one million pixels per display are available. To cover a hemisphere with imagery with resolution of 2 arc minutes per pixel (a typical requirement), approximately 24 displays and 24 CIG channels would be needed. This is not practicable on the grounds of acquisition cost alone; the system would also pose problems in setting up and maintenance which would lead to high running cost. These practical considerations restrict a multiple projector system to five to eight channels, each covering about 70° and giving a resolution of 6-9 arc minutes per pixel. The cost of such a system is still approximately $20M.

As an alternative to generating and displaying imagery over the full FOV required by the pilot for carrying out the necessary maneuvers, imagery can be concentrated in those directions that are most useful to him, resulting in significant cost savings in both image generation and display hardware. This general concept is almost as old as visual simulation itself (one example being in ACM simulation as already described) but it can be implemented in many different ways and new approaches are being developed. It is time that these different approaches were compared and their limitations and advantages discussed. In the rest of this paper, any display in which at least part of the FOV is not fixed in direction relative to the aircraft windows will be referred to as an area of interest (AOI) display.

TYPES OF AOI DISPLAY

The movement of the FOV with respect to the aircraft windows to create an AOI display can be controlled in various ways. The FOV may move with or track:

a. a displayed target
b. the pilot's head
c. the pilot's eyes
d. a combination of the above.

Most of the systems have two fields of view, one set inside the other. To provide a common terminology, the larger FOV will be called the main FOV and the smaller the inset FOV.

Target Tracked Displays: Air-to-Air

In a target tracked system, the inset FOV is placed dynamically within the main FOV ac-

* with acknowledgements to J. H. Burns

cording to the computed position of the target with respect to the pilot's own aircraft. Most applications to date have been of the type described for ACM and gunnery where the target is another aircraft displayed on the inside of a spherical screen in high detail over an inset FOV of about 15°, using a servo directed television projector. The main FOV is provided typically by a wide angle gimbaled shadowgraph projector giving a low resolution, dim image of the horizon, sky and a suggestion of the terrain so that attitude (but not translation) cues are available.

The target aircraft image is superimposed on the sky background and always appears brighter than the sky; this is not usually in accordance with the real world, but is generally considered acceptable. Such a system is efficient in that high detail in the main FOV is not needed and is not provided. Improved aerodynamic simulation has led to several systems of this type being brought into use recently, to give effective training in high altitude ACM.

In the Navy, systems of this type include Device 2E6, the Air Combat Maneuvering trainer for the F-4 and F-14 and Device 2F112, two F-14 Weapon System Trainers (WST). The AOI image is generated using a television camera viewing a plane model mounted on gimbals.

The Navy's Visual Technology Research Simulator (VTRS) has demonstrated the feasibility of applying CIG to an AOI display coupled with a background display on a spherical screen for military applications. Military tasks which have been demonstrated include carrier landing, formation and tactical formation flight, gunnery, air-to-ground weapon delivery and hostile environment maneuvering. Trainers in development which will apply this visual technology concept include the Navy's F-18 Weapon Tactics Trainer (WTT) and the Marine Corps AV-8B WTT. Examples of other target tracked displays include an early Air Force low cost formation flight trainer, which presented a 90° FOV of another aircraft, and the Northrop LASWAVS which presents a 60° FOV from a television camera viewing a modelboard.

Target Tracked Displays: Air-to-Ground

Where a target tracked inset is set against a main FOV the requirements are not particularly stringent, as long as the main FOV is relatively featureless, such as sky (in the case of a target aircraft), or sea (in the case of carrier landing). However, where air-to-ground tasks must be simulated, the ground target area, including the terrain immediately surrounding the target itself, is displayed as an inset at higher resolution than the main FOV (using either modelboard/television camera or CIG image generators), and the system requirements become more stringent in three respects. First, the computation and inset projector servo requirements are more exacting as the inset image has to register with the main image during all maneuvers, whereas air targets do not have a visual reference and small positioning errors are not seen. Second, the distortion of the image constituting the main FOV must be minimized so that when the inset takes up its correct position, the background imagery is also correct. Third, the mode of insetting needs consideration because straightforward superimposition (as for air/air systems) may not be fully acceptable and it may be necessary to "cut a hole" in the background image to make way for the inset. These requirements are considered further in a later section.

Head and Eye Tracked Displays

Before discussing specific head and eye tracked systems, some background will be given on the relevant human characteristics. Figure 1[1] shows the visual field available for a given head pointing direction: binocular vision extends horizontally to $\pm$ 70° and vertically to + 50°, - 70°; monocular vision adds another 30° horizontally each

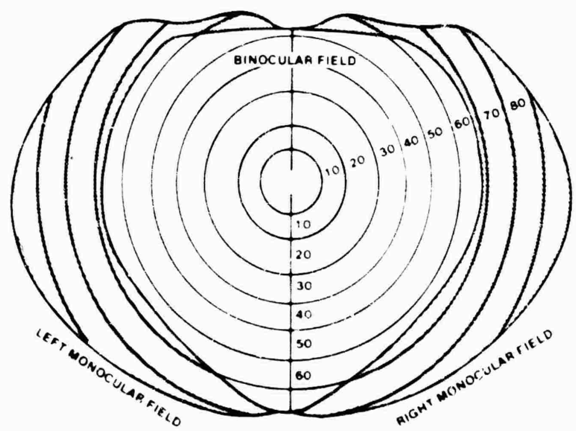

FIGURE 1 - MONOCULAR AND BINOCULAR VISUAL FIELDS

side. Figure 2[2] gives the distribution of visual acuity across the retina, from which it can be seen that for an eye fixated on the center of a 40° diameter spot (and resolving 1 arc minute at the center), the resolution at the edges of the spot will be only about 10 arc minutes. Figure 3[3] is a collation of data from several sources on the range and velocity of head and eye movements encountered for various tasks. From the information in the three figures, it is possible to postulate various display systems that take advantage of human head and eye characteristics for various maneuvers.

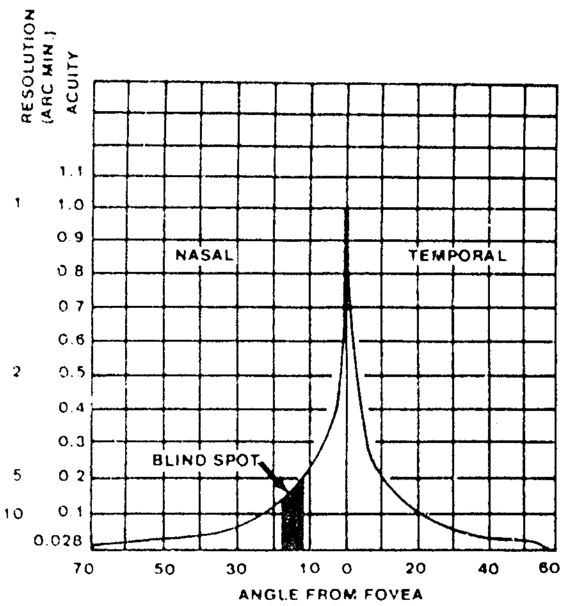

FIGURE 2 - DISTRIBUTION OF VISUAL ACUITY ACROSS THE RETINA EXPRESSED IN DEGREES FROM THE FOVEA

Head Tracked Displays

Consider first a system with head tracking only, i.e., the displayed image is moved so as to keep its centroid always in line with the head pointing direction by monitoring the head attitude continuously with a head tracker and commanding the CIG image generator to compute its image with the appropriate viewing direction. With the eyes pointing straight ahead, a displayed FOV of 140° horizontally and 120° vertically would provide all necessary visual cues except for the peripheral monocular parts of the FOV. Deflection of the eyes by 20° (more than 20° only occurs 4% of the time) adds to these figures to give 180° horizontally and 160° vertically. So it may be said that if head tracking is adopted, there is no point in exceeding an FOV of 180° x 160°.

Actual figures for specific systems will, of course, depend on the training task and the cost effectiveness of providing as large an FOV as this. A head tracked display without any limitation in following head pointing direction, but with a small FOV of say 50° horizontally (a single fixed display of 50° horizontally by 36° vertically has been used for many years by the airlines for landing and takeoff) will enable some maneuvers to be carried out normally. For other maneuvers (see "Intense Visual Search" in Figure 3), an unnatural amount of head movement will be required and it may not be possible to carry out the task correctly. In any event, from some experimental work carried out at NAVTRAEQUIPCEN, a small head tracked FOV is made much more acceptable if the edges are softened, i.e., blended to black. Blending to midgrey is even better in removing the obtrusiveness of the edges of the FOV.

A very important consideration with head tracked displays is the CIG throughput delay. Assuming the head tracker response time is negligible, a change in head attitude will cause a demand for a new view and it is essential that the image presented to the pilot should not move in its apparent direction in space during this period, causing unnatural "swimming" of the image. Once the new image has been computed, it must be displayed in the correct direction. If the head tracked FOV is obtained from a television projector mounted in a fixed relationship to the cockpit structure, the displayed format direction may lag the head direction, but displayed objects must remain fixed in relation to the screen. For systems in which the display, such as one using cathode ray tubes, is mounted on the head, the displayed format moves with the head but compensation of image position is required to avoid "swimming." This point will be elaborated later when different systems under development are reviewed.

One interesting possibility with head tracked displays, if head position in relation to the cockpit is tracked as well as head attitude, is to obtain some of the effects of a collimated display in those systems where the image is viewed on a screen. Movements of the head are measured and fed to the CIG image generator to give a corresponding change in the computed viewpoint. The effect, particularly for sideways movements of the head, is that the objects viewed stay fixed in space with head movement, and this is a strong cue to the distance of objects. The results are similar to what is obtained with a collimated display. CIG throughput delay may be a problem with rapid head movements.

Eye Tracked Displays

Let us now turn to the consideration of eye-tracked displays in which the eye pointing direction of the pilot is monitored continuously and the CIG generates the visual information such that it is always concentrated in the eye pointing direction. From Figure 2, if a single field of view display were to be presented to the pilot in which the resolution decreased smoothly away from the center of vision, the central resolution would be available in all directions in which he could look, but the total amount of information required to be displayed would be very greatly decreased as compared with a system having everywhere a resolution equal to the central resolution. Smoothly varying resolution is difficult to implement but an approximation to the curve of Figure 2 can be made by having a high resolution inset FOV to provide for foveal vision inside a main FOV of lower resolution, with the main FOV image removed over the area of the inset.

In this context, it is necessary to distinguish between resolution and detail, where detail may be defined as density of CIG edges or average number of edges per unit solid

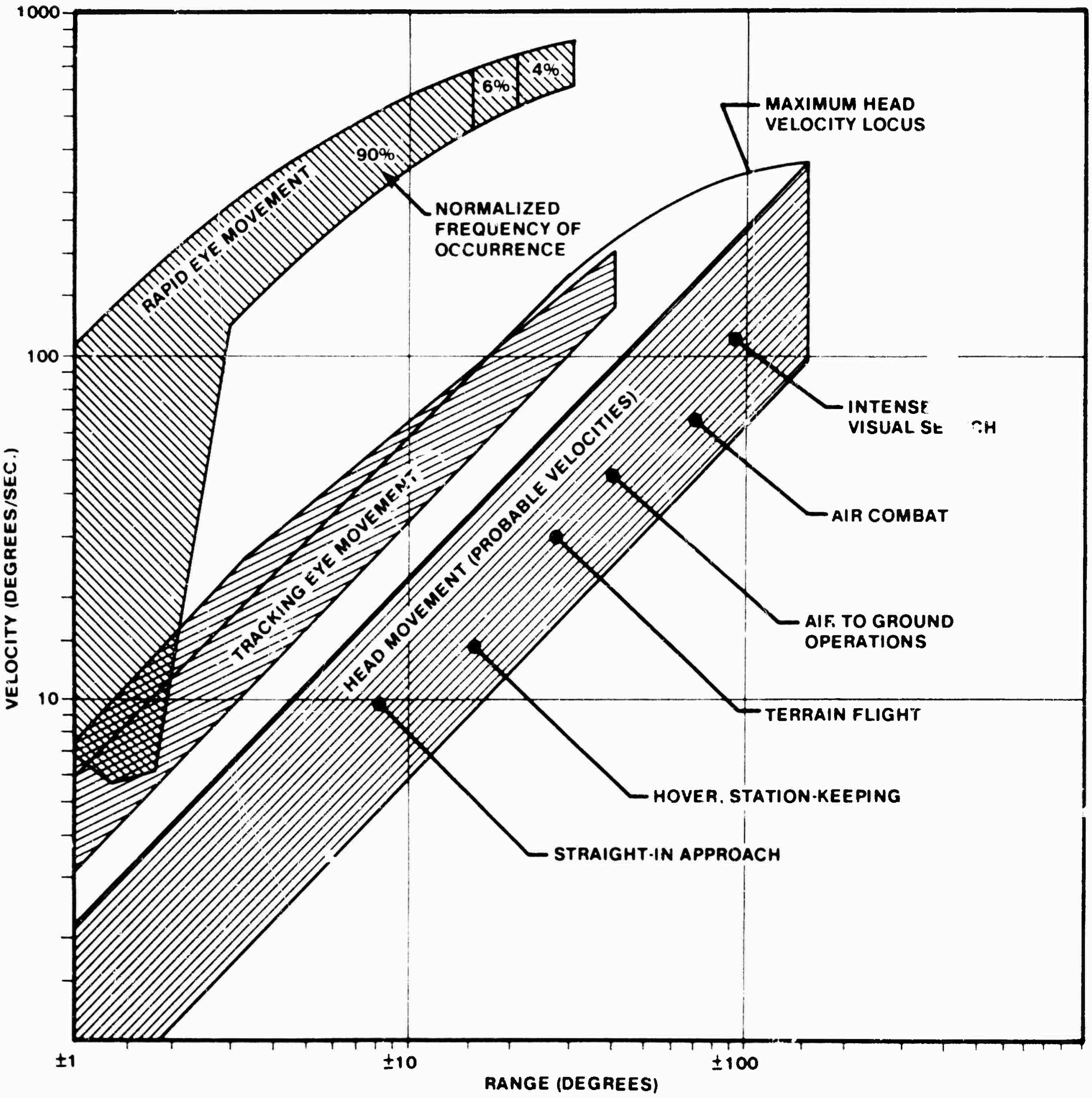

FIGURE 3. RANGE AND VELOCITY OF HEAD AND EYE MOVEMENTS

angle of view. CIG data bases are modelled with a number of levels of detail, e.g., a house at the lowest level of detail is just a block (sufficiently detailed at a large range) but at a higher level it has doors and windows (necessary for close range). An inset may have either higher resolution or higher level of detail (LOD) than the main FOV, or both. For eye tracked systems, high resolution in the inset is necessary and it is uneconomic to provide it in the main FOV also where the eye cannot resolve it. Since the inset occupies only a small FOV, the edge density can be much higher than in the main FOV, although the inset CIG channel does not display more edges than the main FOV. This higher edge density requires a higher LOD from the data base and a higher display resolution. Thus, we arrive at a preferred system in which the inset has both higher resolution and higher LOD.

An important consideration in eye tracked systems is the boundary between the inset and the main FOV. A sharp edge is highly undesirable and a blend between the two over part of the inset area is necessary to avoid visibility of the boundary.

Another important consideration, as for head tracked displays, is the throughput delay of the CIG image generator. When the eye commences a rapid movement from one fixation direction to another, i.e., it commences a saccade, the eye tracker commands the CIG to generate a view appropriate to the new viewing direction. The time taken by the CIG to do this is around 80 msec and the system must be such that the inset is not visible until the image correct for the new direction is available. This means that the eye, if it moves fast enough, will be looking at part of the low resolution main FOV for some milliseconds before the high resolution of the inset appears. At NAVTRAEQUIPCEN, it was considered necessary to carry out an experiment to obtain some practical data on acceptable CIG time delay. Other factors, referred to above, which needed evaluation were the acceptable size for the inset and the width of the blend region in an eye tracked display.

Experiments were performed at NAVTRAEQUIPCEN[4] in which images were projected from a special slide projector to cover a spherically shaped screen surrounding the subject. A variable resolution mask, overlaying the slide, modified the image such that it had a central high resolution area surrounded by a low resolution area with a blend region between them. An eye tracker, using infrared light, measured the azimuthal pointing direction of one of the subject's eyes and drove a rapid servomotor attached to the mask. The subject, therefore, saw a high detail image in the center of his vision at all times. A variable time delay could be inserted between the eye tracker and the servo.

Various masks were used having different widths of blend region; a very small or nonexistent blend region was found to be highly objectionable and distracting to most observers. The experiments indicated that an inset width of 25° within which there is a 5° wide smoothly varying transition region combined with a delay of 80 msec and an eye tracker accuracy of $\pm$ 2.5° would cause noticeable, but not objectionable, perception of the borders of the inset.

This experiment does not provide exact simulation of the appearance of a working eye-tracked visual simulation display, although it gives useful guidelines on the design of such a system. In particular, it does not simulate the appearance of the different levels of detail of a CIG system; this will be discussed in a later section of this paper.

AOI DISPLAYS IN DEVELOPMENT

To advance the consideration of AOI displays, it is necessary to refer to systems currently in development. Table I lists the various Government funded systems. Systems 1 and 2 have a target tracked inset FOV in a fixed main FOV for air-to-ground use; System 3 has a single head tracked FOV; System 4 has a head tracked main FOV with a head tracked inset; System 5 has a fixed main FOV with an eye tracked inset; and System 6 has a head tracked main FOV with an eye tracked inset. In referring to Table I and the following description, it has to be realized that these systems are in various stages of development and the performance data given are target figures for feasibility models only. Not all these systems will be developed to procurement of a fully engineered prototype, but a comparison of them in terms of fundamental advantages and limitations will be valuable in understanding the potential gains with AOI displays. All use displays with 1023 TV line capability.

System 1 in Table I refers to experimental work with VTRS at NAVTRAEQUIPCEN. The main FOV provides a low detail view of terrain from the background projector while the target projector provides an inset FOV of the target area with higher resolution. (Higher LOD for the inset FOV is in the process of being implemented.) The inset can show a group of buildings and part of a road or a group of tanks. Various maneuvers can be carried out, including strafing the target, without losing registration between the low and high resolution images.

To achieve this degree of dynamic registration, the servo response of the target projector had to be optimized. Its pointing accuracy was $\pm$ 1 arc minute under static conditions and 1° at 50°/sec.

Another essential factor, permitting registration of the inset image with the main image, is correction of the distortion of the main image on the spherical screen. This distortion arises due to noncoincidence of the pilot's eyes and the projector exit pupil, the display optics and other factors. The correction is done in the CIG image generator(5) by breaking up long CIG edges into shorter edges and repositioning the vertices to map the scene onto the screen such that the distortion is less than 0.1% from the pilot's eye position. For the inset, the smaller FOV makes distortion correction less critical, but this is being implemented.

The method of adding the inset to the main FOV is simply to overlay the inset image on the background image, as for the target plane in air-to-air simulators. This means that the inset has to be brighter than the background and in fact appears as a fairly well defined bright disc. There is, therefore, no question of the pilot having to search for the target as in the real world; not only is it rendered in higher detail, but it is also brighter. However, once the pilot has acquired the target, the maneuvers he carries out should not be affected by its somewhat artificial appearance. Experimental work with pilots using the technique described will take place next year at VTRS.

System 2 in Table I is the High Resolution Area (HRA) Dual Projector Display system(6) funded by the Army (Project Manager, Training Devices) and procured by the Human Resources Laboratory at Williams AFB. The Advanced Simulator for Pilot Training (ASPT) at Williams AFB has a visual system consisting of seven facets of a dodecahedron structure to provide a wide FOV display. Each facet contains a Farrand Pancake Window optical system and utilizes a large 36 inch diameter cathode ray tube as a display source. The optical elements of the Pancake Window produce an image of the CRT face at infinity.

The Dual Projector Display is an experimental replacement of the CRT by two 1023 line color television light valve projectors fitted with optics to project images onto a back projector screen of the size and shape of the CRT faceplate. One projector provides the main (70°) FOV covering the whole screen and the other, together with a servo driven mirror, gives an approximately 10° inset of high resolution. An important feature of this experimental system is the capability of (a) demonstrating the removal of the main image over the area of the inset (thus "cutting a hole" to leave room for the inset) and (b) demonstrating the effect of various blending functions for the region around the inset. This is a further development beyond simply superimposing the inset as has been demonstrated on VTRS.

The system had reached a certain stage of development in January 1982, and the inset could be moved around within the main FOV. A band of blending between the inset and the main FOV was generated by varying the gain of the video signals from the two projectors in a complementary manner, using eight steps of gain. This demonstration showed that more steps, or a smooth gain change, would be necessary to avoid high visibility in the blend region and also showed the sensitivity of the system to misalignment between inset and main FOV and to the variation of color which occurs across a light valve display (causing color mismatch for some positions of the inset). The experiment was valuable in its impact on future AOI systems.

System 3 of Table I is the Visually Coupled Airborne System Simulator (VCASS) which has been the subject of research by the Air Force Aerospace Medical Research Laboratory (AMRL) for many years. The primary purpose for its development is for aircraft display hardware and crew station configuration development. However, VCASS represents one of the important alternatives in the range of possible techniques for providing a pilot in a simulator with a view in any direction and so must be included here.

The principle of VCASS, as used for simulation, is to mount on the pilot's helmet two small CRTs on which CIG imagery representing the real world is displayed, and to present this imagery to the pilot using a miniature Farrand Pancake Window for each eye. Each Pancake Window presents an image of the corresponding CRT face at infinity over an FOV of 80° horizontally by 60° vertically. These fields can be overlapped to give a total horizontal FOV of between 140° and 100° (with corresponding horizontal overlap of between 20° and 60°). The system is head tracked, i.e., it uses a Polhemus Head Attitude Sensor, which uses a fixed magnetic field radiator, detected by a sensor on the pilot's helmet, to generate data representing the roll, pitch and yaw directions and translational position of the pilot's head. The CIG image generator is controlled by this data to produce the appropriate view for the instantaneous head attitude so that correct imagery is available at all times. To avoid the imagery representing the outside world appearing not only through the windows, but also superimposed on the instrument panel, a CIG model of the aircraft windows can be mapped into the viewing plane (the CRT faces) and used to blank out the image except where it occupies the window area, for the pilot's instantaneous head position and attitude.

The Pancake Windows have approximately 7% transmission for the direct view of the interior of the cockpit over a somewhat smaller FOV than the display. The CIG system currently in use is calligraphic.

As noted earlier, a head mounted AOI display has the characteristic that the slightest attitude change of the pilot's head immediately gives a corresponding change in the direction in space in which the imagery is seen. The CIG responds to the head tracker in computing the new view, but there is a momentary misalignment due to the throughput delay. Referring to the head velocity figures in Figure

3 and ignoring the highest velocities since vision deteriorates beyond about 30°/sec, a minimum figure of 30°/sec may be taken. For a throughput delay of 80 msec, the corresponding momentary angular error in the display is 2.4 degrees. Experimental work at NAVTRAEQUIPCEN (to be described under System 6 of Table I) has shown that the subjective effect of the resultant swimming of the image in a head mounted CRT display is disturbing and some form of correction should be applied. It is understood that improved head attitude sensing algorithms may be developed later for VCASS and no doubt this problem would be addressed at that time.

The concept of presenting an image separately to each eye in a helmet mounted configuration has important consequences. First of all, it makes possible a two-pilot system in which each of two pilots can be given his own independent view of the world (requiring a fair amount of duplication in the image generator). Second, it makes stereo viewing possible, which is being investigated on VCASS. However, a price must be paid in terms of complication: two CRTs and two sets of viewing optics are needed and this increases the weight. Furthermore, fairly exacting adjustments are needed to set up the display for any given pilot, in terms of interpupillary distance, shape of the pilot's head, etc. The concept is being further evolved and miniature color CRTs may be developed and a raster scan CIG may be used later to provide the imagery.

The VCASS system does not have a high resolution inset FOV; this is precluded by the resolution that can be obtained from a miniature CRT. An inset FOV is provided in the second Air Force system, described below, at the expense of greater complexity.

System 4, the Combat Mission Trainer (CMT) is being developed for the Human Resources Laboratory at Williams AFB by CAE of Canada. The display optics are the same as for the AMRL system (miniature Pancake Windows) but four light valve television projectors are used instead of helmet mounted CRTs, the images being relayed to the helmet through coherent fiber optic guides. Two projectors provide the main FOVs for the two eyes and a further pair, each with its own fiber optic guide, provides a slewable inset FOV to each eye.

The potential performance of this system compared with VCASS is greater, in that the high resolution inset (at present head tracked, but possibly, in the future, eye tracked) extends the possible range of use. Whether the performance can be realized depends on some difficult optical design problems. The problems center on the fiber optic guides and associated optics to couple them to the projectors; it is difficult to make coherent fiber optic guides of several million individual fibers without some broken fibers, giving black spots on the display, and such guides are fairly inflexible. By contrast, the VCASS system has only lightweight flexible cables connected to the helmet. The CMT has the same capability for two-pilot display and for stereo viewing. Color is, of course, readily available by using color projectors. Other comments made about the VCASS System are applicable on the problem of CIG throughput delay, the need to blank out imagery falling on the inside of the cockpit and the advantages and problems of presenting images separately to each eye.

System 5 of Table I is the Eye-slaved Display Integration and Test (EDIT) system.[7] The original concept was proposed and partially implemented by Singer Link for the Air Force Aeronautical Systems Division, Deputy for Simulators (ASD/YW), Project 2360, which included an advanced visual system for A-10 and F-16 training. The project was terminated, but some hardware and software became available for experimental use and further work is in progress by Singer Link, funded jointly by ASD/YW and NAVTRAEQUIPCEN, to complete the key components of the system and then integrate them with VTRS for test and evaluation. The data shown in Table I relates to this work and not to the original 2360 specification.

The concept calls for a fixed main FOV from one light valve projector (in a simulator for training the main FOV could be made to cover as large an FOV as desired by using several projectors) together with a "foveal projector" capable of rapid slewing in accordance with output data from an eye tracker and providing a small, eyetracked inset FOV. The foveal projector is mounted rigidly in relation to the cockpit structure in contrast to the helmet mounted arrangement for providing the inset FOV with System 4 (CMT).

This has several consequences. First, movement of the pilot's head does not automatically cause movement of the projected inset image with relation to the screen as is the case where the display is actually mounted on the helmet. The movement of the inset is controlled by the head tracker measuring head attitude change with respect to the cockpit and the eye tracker measuring eye attitude change with respect to the head, the two streams of data being combined to command the foveal projector servos to take up the new pointing direction. There is, therefore, no need to compensate for CIG throughput delay as far as head attitude is concerned. Second, the servo response must be extremely rapid to come near to matching eye movement rates (see Figure 3). Third, because the pilot's head and the foveal projector exit pupil are considerably separated, distortion of the inset image occurs and varies with position in the main FOV, which must be compensated, and the throw distance varies requiring servo control of the projector lens focus.

Finally, to add the inset to the main image, a hole is cut electronically in the main image and due to the variation of distortion with position, the hole shape has to be dynamically varied. A smooth blend is provided around the inset. Some indication has already been given of the possible problem in presenting the new inset image following a saccade, due to CIG throughput delay. Experiments carried out by Singer Link indicate that the phenomenon known as saccadic suppression, which causes the eye to be insensitive for some tens of milliseconds following a saccade, will allow time for the new image to be generated.

The EDIT project is a very interesting one as it aims at the greatest efficiency in generating and displaying imagery by employing eye tracking. Integration of the system into VTRS followed by pilot testing is at present planned to commence early in 1984.

The final system listed in Table I, System 6, Laser Helmet Mounted Display(8,9), has been developed at NAVTRAEQUIPCEN and a complete system is now being procured. Both head and eye tracking are used, the inset FOV being fixed in the center of the main FOV and the resulting combined FOV directed to follow the eye direction in space. The source of light to generate the image is a laser system giving red, green and blue primary colors and the display is viewed on a retroreflective spherical screen. The light is modulated by the video signals from the CIG and scanned in a line by a rotating mirror polygon. Three frame scanners are mounted on the helmet, one for the main FOV, one for the inset, and one for offsets in the line scan direction, each giving a 1023 line raster. Fiber optic ribbons are used to transmit the light to the helmet; these are light and flexible compared with the full frame fiber optic guides required for System 4 (CMT).

The use of laser light, scanned optomechanically, has interesting implications. A system of this kind, unlike a light valve projector, can exhibit absolute uniformity in the intensity of the projected beam over the FOV and there do not appear to be any serious problems in matching the color and luminance of the inset image to the main FOV image.

To prove the concept as far as possible prior to procurement, a mockup was built omitting the eye tracked inset and using a 1023 line CIG signal, to give a head tracked FOV of approximately 25° on a 3 ft. radius spherical retroreflecting screen. Compensation for throughput delay was demonstrated, using the VTRS CIG image generator, by momentary deflection of the raster using offset signals to the line and frame scanners computed from the difference between current head attitude in pitch and yaw and the pitch and yaw attitudes used by the CIG to compute the current scene. The results of the experiment gave confidence that a helmet mounted laser display was feasible; in particular, CIG throughput delay was successfully compensated giving stable imagery. The fiber optic ribbons of 1000 fibers, made to NAVTRAEQUIPCEN specification, have not yet been satisfactory as to the presence of broken or distorted fibers. A ribbon is, however, much easier to make than a full frame guide.

As far as the eye tracked inset is concerned, the work previously discussed(4) gave confidence that, given quick response from the eye tracker, an acceptable result would be obtained. The NAVTRAEQUIPCEN laser HMD system is about to be procured. The plan calls for integration with VTRS commencing part way through FY 85 followed by human factors evaluation during FY 86.

AOI Blending and "Popping"

Before attempting to sum up as to the advantages and disadvantages of the various AOI systems, the question of how well the inset merges with the main FOV for the systems that have an inset should be discussed. First, there is the question of whether the inset is simply superimposed on the main FOV image or a hole is cut in the main FOV image and the inset inserted. Experimental evidence to date favors cutting the hole and inserting the inset provided a blend region giving a smooth change between the two regions is used. However, this has not yet been implemented in a working prototype, and an optimum ratio of width of blend region to inset width needs additional experimentation.

Secondly, there is the question of "popping." As observed previously, an inset FOV has not only a higher resolution, but also should use a higher level of detail (LOD) from the CIG data base than does the main FOV, so that, for example, a runway may be featureless at the low LOD, but have stripes at the higher LOD. In CIG as normally implemented, a higher LOD is brought in as the range decreases and this can be done slowly so that, for example, the runway stripes gradually fade in on top of the previously blank runway. If the stripes occur in an AOI, but not in the main FOV, movement of the AOI may cause them to appear suddenly, and this has been referred to as popping.

For a target tracked system with a fixed ground target, popping cannot occur, although the appearance may be somewhat unrealistic owing to the target area standing out in higher resolution. For a target tracked system with a moving target, a fast target can cause popping, to a degree dependent on the data base.

Eye tracked systems, in which the inset moves within the main FOV, can exhibit popping also but the eye can never, by definition, look directly at the blend region and the eye is operating at lower resolution at the edge of the inset. With head tracked systems, in which an inset is fixed at the center of the

FOV, the eye can look directly at the blend region.

The popping question has been considered sufficiently important at NTEC to lead to a decision to carry out some basic experiments simulating CIG objects by sinusoidal bar patterns of varying spatial frequency and amplitude. It is hoped that this work, to be accomplished during FY 83, will quantify the problem and provide guidelines to CIG modellers on minimizing the effect.

THE OUTLOOK FOR AOI

The trend towards AOI displays due to the excessive cost of implementing wide angle visual systems with multiple projector, multiple CIG channel techniques is likely to continue for a good many years to come. The eye tracked systems offer the greatest potential for high performance to cost ratio, with a resolution of 1 - 1 1/2 arc minutes per pixel in the eye pointing direction (and so effectively in any direction) with the need for only two CIG channels. A key question is whether an eye-directed inset can appear natural to the pilot and whether he will be able to perform with such a system without eyestrain or other physiological problems. It is certainly to be hoped that the funding identified to support the NAVTRAEQUIPCEN HMD and the ASD/YW/NAVTRAEQUIPCEN EDIT remains available as these two systems represent the two main alternatives - on-head mounting and off-head mounting - and only properly carried out integration and test will allow the best system to be chosen.

If eye tracked systems do not, in the end, prove to be practicable, or if they turn out to be more expensive than hoped, a head tracked system such as VCASS may perhaps be developed as a cost effective visual system with more restricted, but useful characteristics. McDonnell Douglas Electronics is working on a similar system, using a VITAL IV calligraphic CIG night scene image generator, giving a 40° circular FOV for each eye and a larger total field with partial overlap. Such systems do not, of course, have the effective resolution of the eye tracked systems.

The resolution may be increased in the center of the FOV to match that achievable with the eye tracked systems by using a system such as the CMT (System 4) in which both the main FOV and the inset FOV move with the head. With such a system it is necessary to turn the head to bring the high resolution area to bear on the object viewed, whereas in the real world situation the eyes move rapidly to acquire objects which are then seen with high resolution. It remains to be determined whether such a different viewing pattern will permit satisfactory training.

The target tracked systems, including the type of system demonstrated for air-to-ground use on VTRS using a target projector do provide an alternative to the eye tracking systems and certainly systems along the lines of VTRS could be implemented with little risk. The value of emphasizing a target by showing it with greater resolution will be explored next year on VTRS using pilots in human factors experiments. We shall have to wait three years or more for validation of the eye tracked systems.

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TABLE I. AOI DISPLAYS IN DEVELOPMENT

System	Main FOV Size*, Resolution**		Inset FOV Size*, Resolution**			CIG Channels	Image Source	Image Presentation	2 Pilot Display	Stereo	Helmet Connections	Color
	Fixed	Head Tracked	Target Tracked	Head Tracked	Eye Tracked							
1. VTRS [illegible]	160° X 80° 7 MIN	-	10° 1 MIN	-	-	2	2 Light Valves	Spherical Screen	No	No	N/A	Yes
2. HRA Dual Projector (PM TRADE/HRL)	70° 4.5 MIN	-	10° 1 MIN	-	-	2	2 Light Valves	Pancake Window	No	No	N/A	No
3. VCASS (AMRL)	-	140° X 60° 4.8 MIN	-	-	-	2	2 CRT	2 Mini Pancake Windows	Potential	Yes	Electronic Cables Only	Potential
4. CMT (HEL)	-	140° X 60° 4.8 MIN	-	25° X 25° or 37° X 37° 1.5 MIN	Future?	4	4 Light Valves	2 Mini Pancake Windows	Potential	Yes	4 Full Frame Fiber Optic Cables	Yes
5. EDIT (ASD/YW/ [illegible])	160° X 80° 8.5 MIN	-	-	-	20° 1.4 MIN	2	2 Light Valves	Spherical Screen	No	No	Electronic Cables Only	Yes
6. Laser HMD [illegible]	-	140° X 100° 8.4 MIN	-	-	27° X 24° 1.5 MIN	2	2 Laser Rasters	Retro-reflective Spherical Screen	Potential	Potential	2 Fiber Optic Ribbons + Electronic Cables	Yes

* Degrees, horizontally X vertically
** Arc minutes per pixel
80° X 60° each eye, partially overlapped

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THE TECHNICAL CONTRIBUTIONS OF THE
TACTICAL COMBAT TRAINER DEVELOPMENT PROGRAM

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ABSTRACT

Project 2360, the Tactical Combat Trainer (TCT), was an Air Force Engineering Development Program to develop two prototype Weapon System Trainers (WST) for training A-10, F-15, and F-16 pilots for combat. Each prototype was to consist of two visual simulation systems integrated with two previously manufactured Operational Flight Trainers (OFT) to form a single WST. The two separate cockpit stations would permit two pilots to "fly" mutual support missions or as opponents in air-to-air combat. The WST was designed to provide full mission training for air-to-air and air-to-surface combat tasks. The TCT prototypes were being developed under contract by the General Electric Company and the Singer Company for a "fly off" to select a production contractor. Approximately two years into the program, these contracts were terminated due to USAF budget problems. Before termination, however, important studies and developments were completed in the visual simulation area by each contractor. Both Singer and GE proposed an Area-of-Interest (AOI) visual system and used Computer Image Generation (CIG). The General Electric approach was based upon a head-slaved AOI infinity image display. The Singer-Link approach was based upon an eye-slaved AOI projected on a dome.

TCT PROGRAM

The Tactical Combat Trainer (TCT) program was to develop a full mission Weapon System Trainer (WST) to train A-10, F-15, and F-16 pilots in combat skills. The WST was to create an environment where the pilot could (1) coalesce all his training from separate sources, (2) experience the heavy task loading of combat, and (3) experience aspects of combat which cannot be trained in the air in peacetime, such as SAM launch, acquisition, and defensive maneuvers or low altitude air-to-air combat. The full mission capability of the WST was to include takeoff, formation (close, route, and tactical), aerial refueling, low altitude tactical navigation, air-to-air or air-to-surface combat, return to base and landing.

Project 2360 was a head-to-head competitive Engineering Development Program to develop two prototype TCT systems, each by a different contractor. These prototypes were then to be evaluated in a "fly off" to select a production contractor to build an additional twenty-six units. Each TCT was to consist of two Government Furnished Operational Flight Trainers (OFT), a visual display for each OFT, an image generation system for each display, modified OFT Instructor/Operator Stations (IOS) and modified OFT Electronic Warfare (EW) simulation systems.

The TCT prototypes were to be designed to be integrated with A-10 OFTs manufactured by Reflectone, Incorporated. The production WSTs would be integrated with F-15 and F-16 OFTs manufactured by the Goodyear Aerospace Company and the Singer Company, respectively. The prototype development contracts consisted primarily of developing the visual simulation system, integration with OFTs, modifying the Instructor/Operator Stations (IOS) and modifying the Electronic Warfare (EW) simulation system. The OFTs, along with their respective visual systems, were to be integrated to permit either two aircraft mutual support missons or flying as opposing aircraft. The IOS was to be designed for a single instructor to monitor and control the simulation for both pilots during integrated operations. Contracts to develop the TCT prototypes were awarded to the General Electric Company, Simulation and Control Systems Department, and the Singer Company, Link Flight Simulation Division, in September of 1978. Just prior to the completion of the Critical Design Review in December 1980, these contracts were terminated due to the USAF funding problems. The termination included residual tasks to complete selected development efforts and the documentation of all studies and developments.

The TCT was designed to permit combat training including evasive flight in a high threat (surface and air) environment; target detection, recognition and identification; and weapon delivery against either air or surface targets. A tactical fighter pilot primarily relies on his vision for target acquisition and tracking, detecting and avoiding threats, maintaining contact with his wingman, and controlling his own aircraft. Thus, the major thrust of the TCT was to provide all the visual cues that the pilot needs to fly combat tasks.

From the inception of Project 2360, it was evident that the visual display portion of the visual system placed the highest demand on technology. Due to the high risk involved, both contractors developed breadboards of the display system to confirm projected performance and to establish subsystem requirements. In addition, many tests and emulations were performed to establish system performance. Prior to termination, both contractors were able to complete the development of specific display components.

Since Project 2360 was a competitive program, information concerning the technical aspects of the program was not published. Due to the termination of the contracts, this information can now be presented. This paper will describe the TCT requirements, the technical approaches, design performance, and results of the development efforts. Although many developments and analyses were completed, this paper will primarily address the visual simulation developments with emphasis on the visual display.

TCT REQUIREMENTS

The requirements for the TCT evolved from the combined visual system requirements of the Required Operational Capabilities (ROCs) for the A-10 (Nov 76) and F-15 (Jul 76) and the requirements letter for the F-16 (Aug 74). Each of these documents required a full mission WST which consisted to two OFTs with full (same as the aircraft) field of view (FOV) visual simulation. Each WST was to be capable of independent (individual) or integrated (mutual support or opposing) flight for all tactical fighter training and tactical (combat) roles of the aircraft. These roles included takeoff and landing, formation flight, air refueling, low altitude tactical navigation, air-to-air combat and tactical air-to-surface tasks.

Separate research visual systems had been developed and had successfully trained air-to-air combat at medium altitude, takeoff and landing, and limited formation tasks, but no systems existed to support low altitude tactical navigation, tactical air-to-surface tasks, or low altitude air-to-air combat.

Project 2235 (PE 64227F), the Air-to-Ground Visual Simulation Demonstration, was initiated by the Deputy for Simulators in 1975 to evaluate visual simulation technologies potentially applicable to air-to-surface weapons delivery training. The evaluation of three somewhat modified visual systems by tactical fighter pilots performing both training and tactical tasks showed that indeed more capability existed than was previously thought. The demonstration included both camera model and CIG image generators, optical mosaic and dome displays, and the feasibility of both head slaved and target slaved areas of interest (AOIs). The demonstration included both subjective evaluation and objective measurement of the technical characteristics of each device. The basic recommendations of Project 2235 were two-fold: first, begin procurement of a production prototype of a CIG/Optical Mosaic visual system, and second, pursue research and development of a CIG/Dome visual system including further definition of area of interest requirements. In addition, the demonstration pointed out the need for further development to meet the Tactical Air Command (TAC) requirements.

Further evaluation of the technical visual system requirements in the two primary task areas, tactical air-to-air and air-to-surface combat tasks, revealed that the requirements were so similar that a single device was the preferred approach. The display resolution requirements for air-to-air combat against a MIG-21 size target are essentially the same as the resolution requirements for a tank size target for air-to-surface weapons delivery. Also, when the highly likely scenario of offensive or defensive air-to-air combat at low altitude is considered (a scenario not practiced in the aircraft for safety reasons) the visual cues required are also very similar. All three aircraft, the F-15, F-16, and the A-10 can expect to engage or to be engaged in low altitude air-to-air combat. A thorough analysis of training and tactical (combat) tasks and the accompanying technical requirements for a visual system strongly support the development of a single visual system for training in both task areas.

Armed with the stated user requirements, demonstrated air-to-air simulation capabilities, and the results of Project 2235; work was begun in 1977 on the specification and statement of work for what became Project 2360 (PE 64227F), the Fighter/Attack Simulator Visual System (F/ASVS), later known as the Tactical Combat Trainer (TCT) program.

A functional specification was developed for Project 2360 to encourage the competing contractors to use their skills and to be innovative to meet the training requirements of the user. Special care was taken not to preclude a particular technology if it appeared to have any potential to meet the training requirements. The technical requirements for the visual display specified a minimum FOV and some limited optical and alignment characteristics based upon previous work. Image alignment requirements were based upon training task requirements, the most stringent alignment in front of the Heads Up Display (HUD), where it is more critical. A CIG system was required as an image source because of its inherent flexibility and the ability to permit a large gaming area. Imagery requirements were related to task requirements.

To supplement the technical and performance requirements for the visual system a set of four annexes to the specification were developed. These annexes described the planned use of the TCT system. These annexes were:

Annex A: Representative Task List and Generalized Scene Content

Annex B: Concept of Training

Annex C: Prototype Visual Data Base

Annex D: Maintenance Concept

The annexes were developed in concert with TAC to provide a thorough orientation and a ready reference for the contractor to use throughout the program. Annex A contains a comprehensive discussion in layman's language of each task to be trained, how each task is performed, and the visual references used to perform the tasks. All tasks and discussions were oriented toward tactical (combat) tasks as opposed to the normal orientation toward initial qualification training. Most of the TAC training requirements are continuation (recurring) training for mission ready tactical fighter pilots which consist primarily of tactical tasks. These tactical tasks have a significant impact on the visual system requirements.

To document his particular approach, each contractor was required to prepare a Contractor Prepared Prime Item Development Specification

(CPIDS) which was put on contract and updated as his design became better defined. Annexes A through D were included as part of the CPIDS.

The technical requirements imposed upon the competing contractors fell into two basic categories: (1) Training Task Requirements and (2) System Design and Performance Requirements. The primary drivers were the training tasks and the contractors were encouraged to be innovative making system performance tradeoffs to meet the training task requirements.

The training task requirements included 102 tasks which may be grouped into six basic task sets. These basic task sets are: Air-to-Air, Air-to-Surface, Formation, Low Altitude Tactical Navigation, Aerial Refueling, and Takeoff and Landing. Table 1 lists the basic task sets and representative tasks within each set.

TABLE 1 TRAINING TASK REQUIREMENTS SUMMARY

Air-to-Air

- Basic Fighter Maneuvers
- Basic Counteroffensive Maneuvers
- Gun Tracking
- Missile Employment
- Air Combat Tactics
- Low Altitude Intercepts/Engagement
- Visual Missile Trace Use
- AAA/SAM/AI Detection/Avoidance

Air-to-Surface

- Scorable Range
  - Box Pattern
    - Bomb, Strafe, Rockets
- Armed Reconnaisance
- Forward Air Controller Operations
- Tactical Deliveries
  - Pop-up
  - Random Attack
  - Tactical Bombing
- Moving Target Attack
- Guided Weapons
- AAA/SAM/AI Detection/Avoidance

Formation

- Takeoff, Landing (Lead/Wing)
- Close, Route, Trail
- Tactical
  - Air-to-Air
  - Air-to-Surface

Low Altitude Tactical Navigation
- Target Acquisition

Aerial Refueling

- Tanker Rendezvous
- Observation Position
- Precontact Position
- Contact Position

Takeoff and Landing

- Single Ship
- Overhead Traffic Pattern
- Closed Traffic Pattern
- Circling Approach

Air Force system design and performance requirements were primarily written in terms of performance of the training tasks rather than implementation and design specification. The only implementation directed was the use of a CIG system as an image source. Special precautions were taken to avoid precluding potential technologies. Table 2 lists examples of the basic requirements grouped into categories. The requirements were later specialized by each of the two contractors to define their particular approach to solving the training problem.

After contract award, unique methods were employed to insure that both the contractors and the users fully understood the significance of the system requirements throughout the program. Starting during the second month of the contract, Contractor Orientation Visits were made to operational bases. These visits included opportunities to look at, photograph and measure the aircraft and weapons; to discuss tasks and visual cues with pilots; to see films and video tapes of tasks being performed; and to ask questions of the pilots until the contractors understood the tasks. No questions were too trivial to ask. Orientation visits were held with A-10, F-4, F-15, and F-16 pilots and Tactical Fighter Weapon Center Penetration Aids Instructors to cover all aspects of the planned use of the ~~TCT~~ system. The contractors

TABLE 2 TCT TECHNICAL REQUIREMENTS/GOALS SUMMARY

System Requirements

- Independent/Interactive
- Correlated In-Cockpit/Visual Cues
- Object/Pattern/Light Size, Position
- AOI (If Proposed) Position
- HUD to Visual Alignment
- Geometric Distortion
- Moving Vehicles
- Visual Effects
- Monochrome (Color-Goal)
- AGM-65B Maverick
- Channel Misalignment
- Transport Delay
- Safety
- Instructor Operator Station
- Availability/R&M Goals
- Computational System Requirements

CIG Requirements

- Basic Image Content
  - Expanded in Annex C
  - DMA Terrain, Cultural Data
  - Model to Meet Training Requirement
- Performance
- Accuracy
- Special Effects (Haze, Clouds, etc.)

Display Requirements

- Field of View
- Collimation
- Head Motion Evelope (Minimum)

NOTE: Contractors were encouraged to be innovative and to make tradeoffs to meet training requirements.

showed extensive learning with these visits and developed a strong operational orientation. This had a very positive impact on both system analysis and design, and the morale of the persons assigned to the program. A true mission orientation developed. The questions became more incisive during subsequent visits and caused the pilots to really look at how and why they performed each task. Pilots attended each design review to continue the operational inputs. Data base visits were also conducted at bases to be modeled. Data base modelers were able to discuss the significance of features with pilots, to look at and photograph features, and to collect drawings of airfield layouts. Reconnaisance photography of gunnery ranges and low altitude tactical navigation routes was also provided.

The orientation and data base visits made major contributions to a thorough understanding of the requirements and to the development of a sense of mission on the part of contractor personnel. Design tradeoffs were then made after an analysis of the effect on mission performance instead of on strictly cost or technical considerations.

GENERAL ELECTRIC'S APPROACH

General Electric's approach to the TCT visual system was based upon an expanded and modernized Advanced Simulator for Pilot Training (ASPT) display. The expansions included increasing the field-of-view (FOV) to provide coverage essentially limited only by aircraft structure and the addition of a High Resolution Area (HRA) inset into the lower resolution backgroud. Figure 1 is an artist's concept of the TCT WST as designed by GE.

The visual system was to use a common approach to generate and display all imagery. A CIG system would produce eight channels of video which were to be displayed to the pilot on ten CRTs and viewed through a dodecahedron arrangement of ten pentagonal Pancake Window(R) virtual-image optical units. The image presented to the pilot would consist of a helmet-slaved high resolution area (HRA) centered within a large high detail background area of interest (AOI) and a low detail background/horizon filling out the remainder of the display as shown in Figure 2. With the Maverick missile selected, one channel of video would be dedicated to the Maverick monitor and the remaining seven channels allocated to the visual display. The two or three channels which did not contain CIG imagery would be behind the pilot and would have a horizon display to provide a peripheral horizon and illumination in the cockpit.

The insetting of the HRA was to be accomplished electronically by sequentially scanning alternate fields of the full raster and a miniraster. The miniraster consisted of 600 scan lines and 600 pixels per scan line. The full channel raster consisted to 888 scan lines with 888 pixels per scan line. The field-of-view (FOV) of the HRA is 15 degrees, circular, providing a resolution of 1.5 arc minutes. The average resolution of the full channel raster (for both high detail AOI and background) is 6 arc minutes. Both the HRA and high detail AOI display the same high detail scene content and provide most of the visual cues to the pilot. The low detail background scene contains the terrain outline, horizon and representative alerting cues such as a SAM launch, wingman or an air interceptor. The high detail AOI FOV is 120-

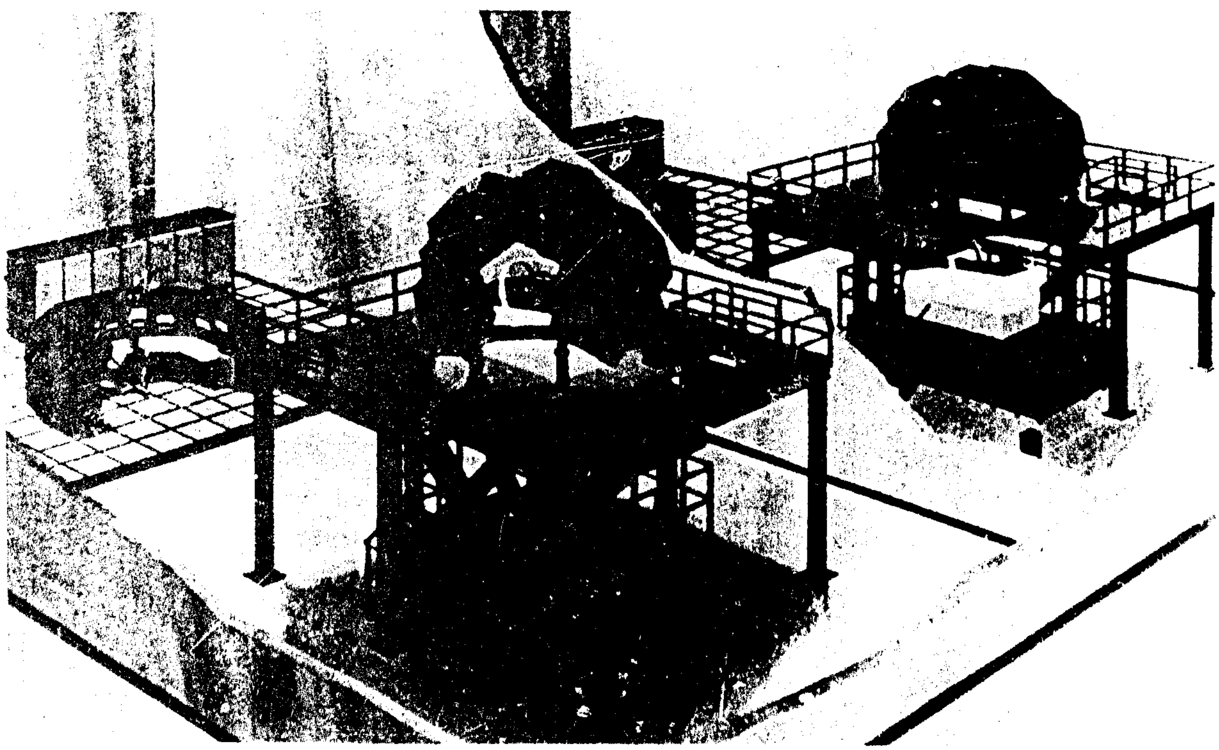

FIGURE 1 Artist's Concept of General Electric's Approach to the TCT WST

degrees, horizontal, and 80-degrees, vertical. This AOI FOV is based upon an AFHRL air-to-surface weapon system delivery study that evaluated pilot performance for various FOVs. The HRA remains centered in the high detail AOI and both are directed about the total FOV of the display by a Helmet Mounted Sensor (HMS). Thus, the highest scene content will be displayed to the pilot in the direction his head is pointed with the high resolution area for target acquisition centered within the area of the highest scene content. Blending is provided in the HRA to minimize the effects of a distracting boundary with the background imagery. This all electronic AOI approach requires no electromechanical servo mechanisms. This display approach has no constraints on the number of high resolution aircraft or ground targets which may be simultaneously displayed to the pilot, since the target will appear at high resolution whenever the pilot places the target in the HRA.

While the helmet-slaved AOI approach was adopted to avoid false "searchlight" cues which would pinpoint the targets, there was operational pilot concern that, because the HRA is centered about the helmet line of sight, the HRA could not be directed to the "6 o'clock" position and that unnatural visual scan patterns would be necessary in the simulator since the head must be moved to control the HRA to acquire targets. It should be noted that the General Electric visual system could also position the HRA along the pilot's line of sight (LOS) by using both eye and head position measuring devices.

The CRTs, developed by Thomas Electronics for General Electric, are 36-inch diameter metal funnel CRTs with a dispenser cathode electron gun. It was necessary to develop the metal funnel CRT technology in order to reduce significant schedule risks and cost associated with the use of glass funnel tubes in the TCT production phase (as well as for safety considerations during manufacturing). The CRT developed for the TCT program is the largest metal funnel CRT ever developed. This technology is presently being used to fabricate replacement CRTs for both ASPT and Simulator for Air-to-Air Combat. Figure 3 is a photograph of the metal funnel CRT in process before application of the phosphor screen.

To drive the CRTs, the display electronics accept the video signals generated by the CIG system and produce signals for driving each CRT in such a manner that the proper view is provided to the pilot. The geometric distortion requirements placed upon the system required that the CRT sweep signals be very accurate. The display electronics subsystem designed and breadboarded by GE was capable of providing these sweeps, including the compensations for CRT to image plane mapping and Pancake Window(R) mapping functions. The magnitude of the compensations, the need for inset raster capability, and the accuracy requirements led to an approach using linear feedback deflection amplifiers to track precorrected sweep signals.

Breadboard CRT electronics were fabricated and tested which sequentially scan a full channel raster field, a mini-raster field, a full channel raster interlaced field and mini-raster interlaced field. In addition to the dual scanning format, the electronics would position any part or all of the inset anywhere within the channel FOV. Figure 4 is a photograph of the 36-inch CRT with the mini-raster overwriting the full channel raster using breadboard CRT electronics. The mini-raster is scanned in a square format as shown in the figure. The blanking for the round format and the insetting and boundary blending is

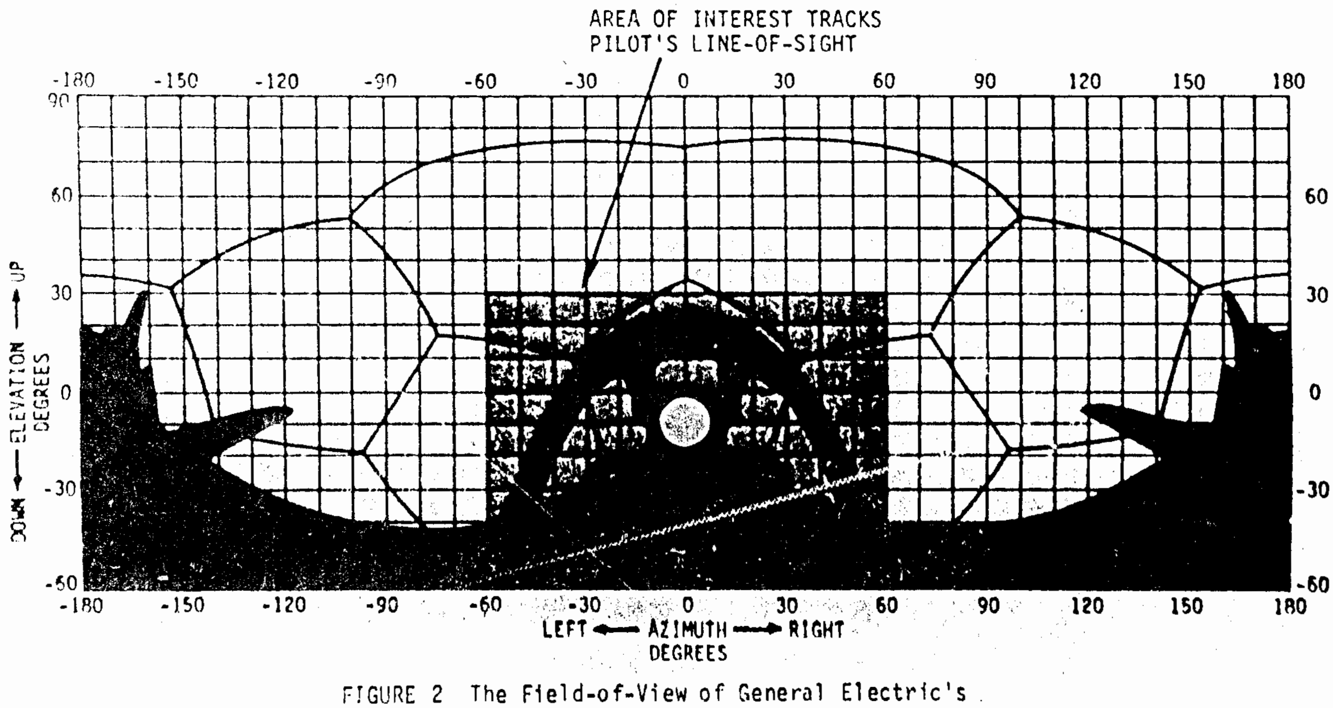

FIGURE 2 The Field-of-View of General Electric's Visual Display and Area-of-Interest (The white circle represents the HRA)

generated by a CIG system. Since the CIG system generates a scene with a "Tan θ" mapping and the Pancake Window(R) is true angle mapping, the CRT electronics must compensate the raster format on the CRT to display an undistorted image to the pilot. This compensation also requires that the circular HRA be scanned as an ellipse on the CRT as the HRA moves from the center of the channel. Tests were conducted which showed that the registration error on the HRA to the full channel raster was less than 0.40 degrees within the total FOV, less than 0.15 degrees within the instantaneous FOV and was much less near the center of the channel. Overall, the breadboard CRT electronics met all the TCT distortion specifications except in a few areas at the edge of the CRT. In addition, the breadboard CRT electronics, operating with a 36-inch CRT, met or exceeded the resolution and MTF requirements without considering the effects of the Pancake Window(R). This was a significant advance in the state-of-the-art of display technology.

The In Line Infinity Optical System (ILIOS) consisted of ten Farrand Optical Company Pancake Windows(R) and a dodecahedron shaped support structure. Each optical unit has a 24-inch focal length and is pentagonally shaped. When juxtaposed in the dodecahedron, the ten windows provide a continuous field of view from the pilot's eye reference point. The designed and manufactured ILIOS is similar to the ASPT system with two significant differences:

a. Although the dimensions of the individual Pancake Window(R) and dodecahedron are the same as the ASPT system, the orientation of the ILIOS relative to the cockpit is different in order to accommodate three additional channels and, therefore, a larger FOV.

b. Improved Pancake Window(R) fabrication techniques resulted in reduced defects and imperfections in the optical elements.

The overall specified performance on the General Electric visual system is summarized in Table 3. Before termination of the contract, GE had completed and tested a breadboard of the CRT electronics with a glass funnel CRT. These breadboards met or exceeded all TCT specifications. A 36-inch metal funnel CRT, the largest ever built, was developed, fabricated, and tested. When tested this CRT met all requirements except for the resolution of the HRA raster. This lower resolution was attributed to the newly designed electron gun used for the test. With these developments, the overall technical risk of the General Electric concept was significantly reduced. However, the training risk of the helmet-slaved HRA remains and requires further evaluation with a pilot in the loop. Currently, no such effort has been funded to resolve this question.

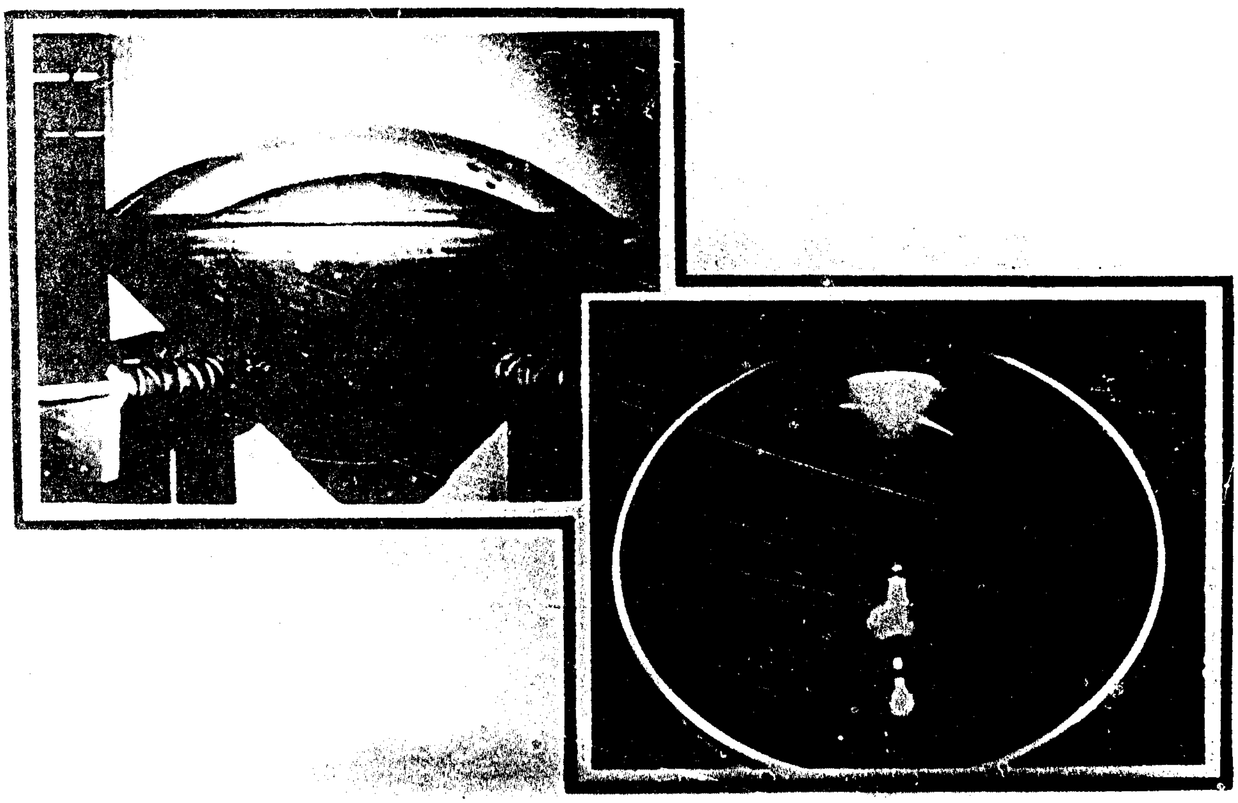

FIGURE 3 Thirty-six Inch Metal Funnel CRT in Process Before Phosphor Application

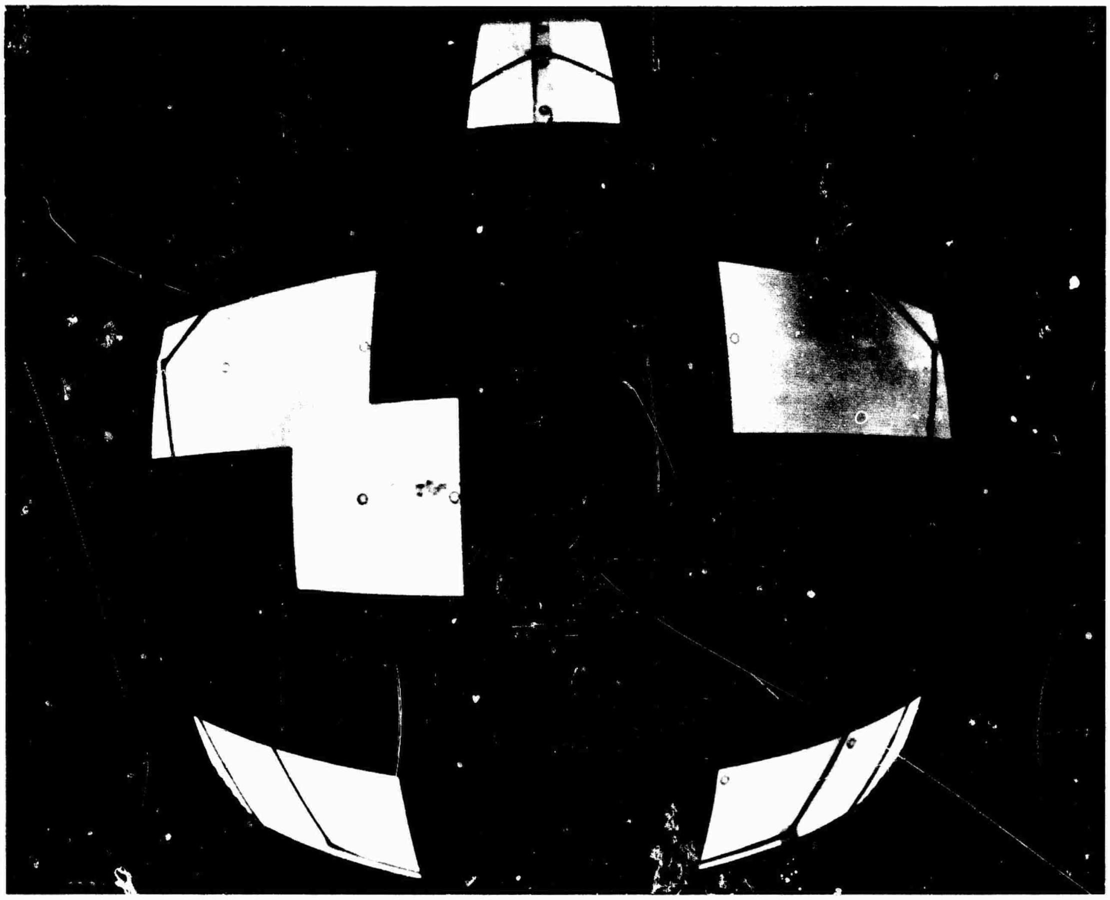

FIGURE 4 The High Resolution Mini-Raster (Off Center) Shown Inset Into the Background Raster, Visual Display

TABLE 3 GE TCT PERFORMANCE PARAMETERS

Total Field of View:	Essentially same as aircraft
High Detail Area of Interest:	120 degrees Horizontal, 80 degrees Vertical
High Resolution Area:	15 degrees Circular
Full Channel Resolution:	6 Arc Minutes, Average
High Resolution Area (HRA) Resolution:	1.5 Arc Minutes
Brightness:	6 Footlamberts, Highlight
Contrast Ratio:	15:1 Minimum, 25:1 Nominal
Number of Edges:	4000
Number of Point Features:	4000
Number of Circular Features:	1000
Video Raster Lines:	888 Background, 600 Mini Raster
Edge Crossing/System Line:	400 Background, 220 Mini Raster
Edge Crossing/Channel Raster Line:	256 Background, 220 Mini Raster
Moving Model Types:	Airborne, 10 Types Ground, 50 Types
Environment:	Full Weather, Time of Day Effects
Scene Enhancement:	Articulated Parts, Curved Surface Shading
Surface Texturing:	Circular Features, Curved Surface Shading, Point Features, Gray Shade Variations
Visual Data Base:	Both Transformed DMA and Hand Models
Gaming Area:	1380 NM x 1380 NM

SINGER-LINK'S APPROACH

The Singer-Link approach to TCT exploited the fact that the high-resolution viewing area of the eye is relatively small. This high-resolution area is the fovea of the eye, which is the only area where small details may be perceived.

Surrounding the fovea is a peripheral area where the resolution of detail is low but, because of the way human vision operates, there is a high sensitivity to movement. The psychophysics of human vision creates an image in the "mind's eye" of building a total high-resolution image of the real-world scene from a series of small high-resolution "snapshots", each of which is surrounded by lower-resolution information. If this situation is emulated in the visual system, the FOV requirement for instantaneous high resolution and high detail is greatly reduced. Thus, the capacity of the image generator can be concentrated where it will be used and the number of image display channels may be reduced.

In the visual system, the pilot's line of sight (LOS) is monitored and a high-resolution, high-detail area; surrounded by a large low-resolution, low-detail area; is displayed along this LOS. When the eye's LOS changes, this is sensed and the high-resolution area is moved accordingly, matching the eye's ability to discern high detail in only a small area of the total scene at any one time. The net result is the impression that there is high-resolution, high detail imagery everywhere.

The TCT eye-directed AOI visual system provides the pilot with high resolution and high detailed imagery anywhere within the pilot's FOV. This is accomplished by projecting a 20 degree monochrome image on a 35 ft diameter dome wherever the pilot looks out the cockpit. This 20 degree foveal image is directed along the pilot's LOS using servo driven foveal projectors. This foveal image is inset into a lower resolution and lower detailed monochrome peripheral image that is projected onto the dome through fixed wide angle peripheral projectors. Figure 5 shows the layout for the projectors coupled to an A-10 OFT. It requires four foveal and four peripheral projectors to provide an unobstructed FOV to the pilot. The four peripheral projectors are located at the four corners of the simulator (45 degrees to the cockpit axis system) and are optically merged to form a continuous 360 degree image to the pilot. However, the CIG instantaneous field of view is limited to 180 degrees azimuth and 120 degrees elevation along the pilot's LOS to concentrate the scene detail capability of

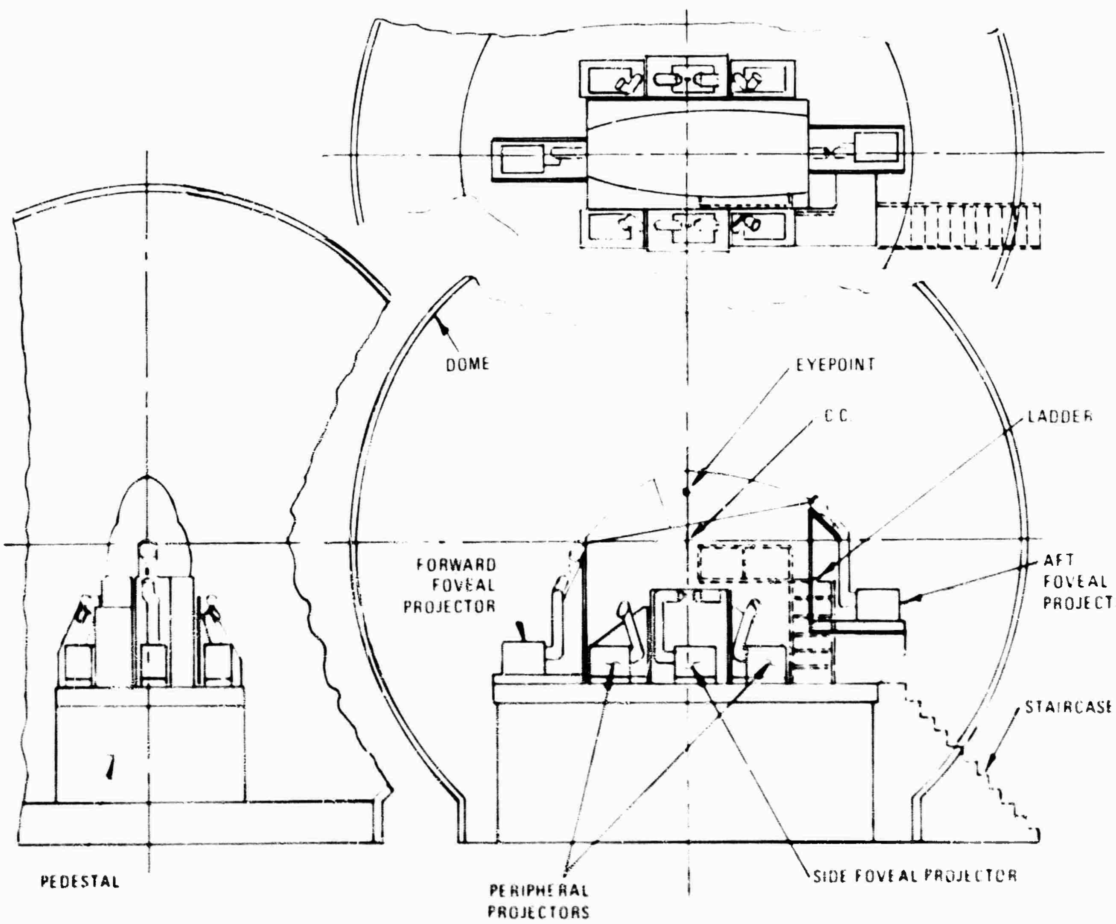

FIGURE 5. The Layout of Singer's Visual Display Approach on an A-10 OFT

the CIG. The four foveal projectors located on the cockpit axis system (forward, aft, left and right) have overlap on the dome to permit the switching of foveal projectors without loss of imagery. Therefore, only one foveal projector is required at any instand to provide the foveal image along the pilot's LOS. The imagery for both the foveal and peripheral projection systems is generated by a single five channel CIG that supplies 874 active lines with 922 pixels per line. This provides better than 1.4 arc minute resolution everywhere within the total simulated aircraft field-of-view. In addition, two very important visual cues, head motion compensation and realistic G-dimming, are inherent in the eye-directed approach.

In real-image displays, there is an inherent problem of image placement as a function of head motion. In previous dome displays as the pilot moved his head, the simulated imagery would appear to be located on the projection screen. The eye-directed system solves this problem by using the helmet positional information to move the imagery in response to the pilot head motion. This results in correct image motion so that objects located in infinity move as if they were at infinity and objects at, say, 5 feet move as if they were at 5 feet. This is accomplished by providing to the CIG eyepoint position and projector/screen/eyepoint geometry data. The result is imagery that moves as it should relative to the pilot changing viewpoint not only with respect to the data base but also with respect to the projection geometry.

The visual cue associated with pullint G's is a familiar visual effect used by experienced pilots of high performance aircraft. As the pilot pulls higher G's over given periods, his FOV will normally start to collapse, and if the G-level is sustained, the FOV will eventually collapse to zero. This collapse could be fully simulated in the TCT visual system. The initial collapse down to 10 degrees from the foveal is handled by the peripheral hardware with the collapse from there to zero being handled in the foveal merge hardware. In an air-to-air mission, the TCT visual system will allow pilots to "fly the tunnel" when engaging another aircraft at short range. In this maneuver the pilot attempts to keep the target within the fovea while maintaining sufficient G's to provide an almost but not totally collapsed FOV.

EYE PSYCHOPHYSICAL REVIEW

The human vision system provides highly detailed information about the relative positions, reflectances, and visible emissions of very small elements in the visual world. It also senses changes and rates of change in scene element positions, and supports the examination and tracking of these elements.

Highly detailed vision is maximized in a relatively small area in the center of the eye, approximately 5 degrees in diameter, known as the fovea. The eye is sensitive to light as far out as 90 degrees from the fovea. But, in the area beyond 10 degrees, the functions are primarily to alert the person to the presence and general activity of the scene elements.

Figure 6 depicts the resolution falloff of the eye as a function of angle from the fovea.

The movement of the eye is called a saccade. These saccades are the eye's way of moving new elements into the fovea for detailed examination. Saccadic motions are typical of voluntary shifts of attention from one scene element to another and take place at relatively high speeds and accelerations. The speed of a saccade depends on the distance to be scanned. Experiments indicate that the eye tends to maintain fixation on a scene element for a minimum of about 250 milliseconds, moving to new scene elements with peak velocities of 700 degrees per second with accelerations of about 50,000 degrees per second squared.

During these high-speed eye movements, scene information is passing very rapidly across the fovea and is not apparent to the observer. This visual suppression process precedes the start of a saccade, continues on through the saccade with perception not fully returning until some time after the cessation of eye motion. For example, one is unable to see one's own eye movements in a mirror when looking from one eye to the other.

The previous discussion was for static scenes only. In the dynamic scene situation, the eye can smoothly maintain points of interest within the fovea for objects moving up to about 100 degrees per second. During these tracking motions, the scene elements of interest remain relatively fixed to the fovea and thus there is no need for visual suppression. Even so, visual acuity does decrease as the tracking velocity increases. At high velocities, up to 200 degrees per second, the eye uses a combination of saccadic motions and tracking motions to maintain the object within the fovea.

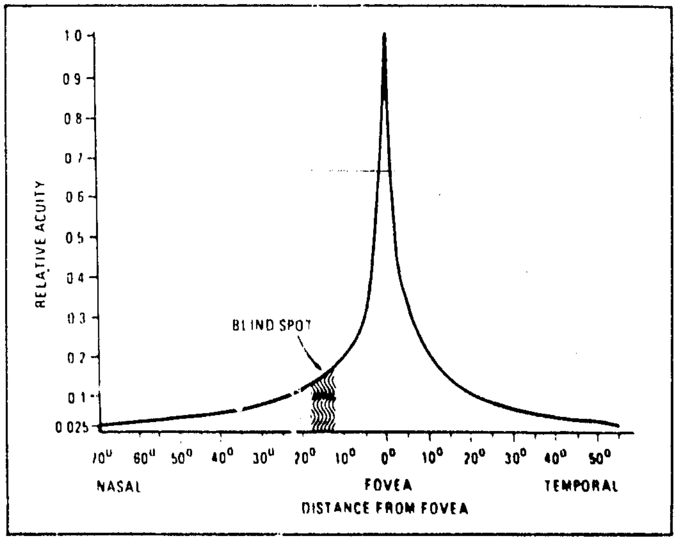

FIGURE 6 Relative Visual Acuity as a Function of Angle from Fovea

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The smooth eye motion used to track moving objects cannot be voluntarily induced without the presence of moving imagery. It is difficult to prevent one's eye from following images that fill a large portion of an observer's field of view. As an example, one can observe someone trying to move his eyes smoothly down a typed page. It cannot be done without the aid of a pointer smoothly moving down that page. Also, if the observer "focuses" on a page and the page is moved smoothly, the eyes will track the page's motion.

DISPLAY SYSTEM

The design of the TCT visual display system was based on these two characteristics:

(1) Visual acuity as a function of angular distance from the fovea, and

(2) Suppression of visual perception during eye motion.

The first characteristic permits the concentration of image detail and resolution in the region where the eye is looking. Figure 6 suggests that high resolution and detail in the peripheral regions are unnecessary. The suppression of visual perception before, during, and after a saccade, provides the key to the feasibility of a visual design which is optimized on the eye's angular acuity falloff. Without the period of visual perception loss associated with a saccade, the bandwidth requirements to position the foveal image would be well beyond the state-of-the-art.

The eye-director AOI display approach for TCT was developed around five major hardware systems.

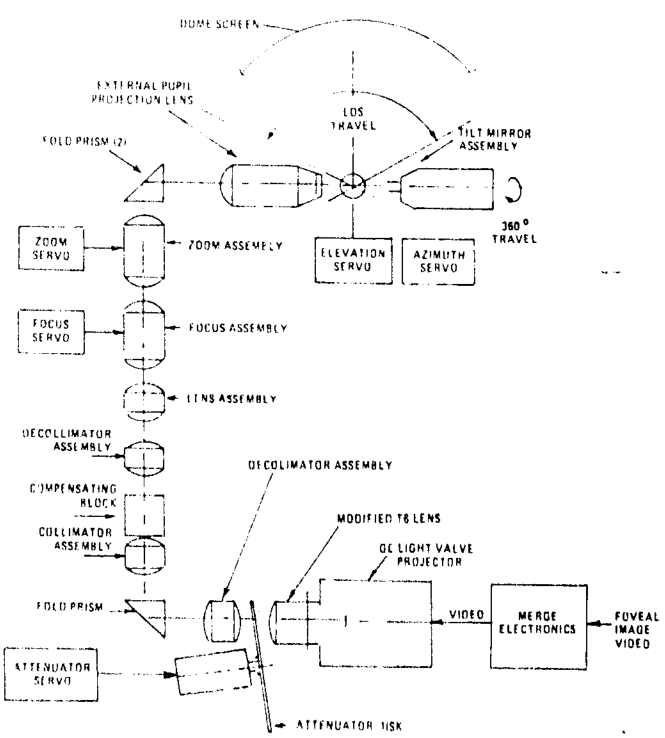

FIGURE 7 Foveal Projector Diagram

(1) Foveal projection system

(2) Peripheral projection systems

(3) Helmet mounted oculometer system

(4) Dome display screen

(5) CIG

FOVEAL PROJECTION SYSTEM

Figure 7 shows the components of a single foveal projector from video input to the dome screen.

The foveal projection lens has an external pupil and is approximately telecentric. The external pupil allows the servoed mirror to be made small by imaging the pupil on it. The first advantage is obvious: the servos used to drive the mirror can be made smaller as the load size is made smaller. The second advantage is an increase in excursion without vignetting as compared to a system without an external pupil.

As shown in Figure 7 there are five servos in the foveal projector; two control LOS, two control size and focus, and one controls brightness. The servo rates and accelerations are designed to be consistent with the requirements of an eye-directed AOI. Link has breadboarded a complete foveal projector that fulfills these requirements. The azimuth/elevation servos control the LOS of the foveal image. This image can be pointed anywhere except where occulted by the projection lens or azimuth/elevation servos. By the nature of this system, the image must be derolled as the azimuth servo rotates; this function is accomplished in the image generator. The zoom/focus servos control the size and focus of the projected foveal image. Due to the geometry of the display system, the throw distance and apparent AOI FOV size to the pilot will vary as a function of his LOS. In order to maintain a constant AOI FOV size to the pilot, the projected FOV must be varied as a function of the pilot LOS. In addition, the image must be refocused as the projection throw distance varies. Both these functions are controlled by zoom and focus. The attenuator servo controls the brightness of the projected image. Because of the geometry, the brightness of the imagery before reaching the screen must be varied as a function of the pilot LOS in order to maintain a constant apparent brightness to the pilot. The main contributing factors to the variance are (1) screen gain, (2) angle of incidence and reflectance with respect to the pilot, and (3) projected FOV. The brightness of the output image is controlled by rotating a variable-density disk located within the optical path.

The light source for the foveal projector will be provided by a GE light valve projector (PJ7150). This light valve provides a light output of 1,000 lumens with a minimum resolution of 800 by 750 TV lines per picture height resolution. The light valve will be modified to a 1:1 format rather than the standard 4:3 format, to reduce the losses in foveal image circular FOV. The modifications will result in a usable light output of 750 lumens and a resolution of 800 TV lines horizontal and 750 TV lines vertical.

The brightness of the outside 3 degrees of the foveal image is reduced to blend/merge the foveal image into the peripheral imagery. This blending is accomplished by electronically feathering that area of the foveal system as a function of angular subtense to the pilot eyepoint. The reverse is done in the peripheral merge electronics.

PERIPHERAL PROJECTION SYSTEM

Figure 8 shows one of the four peripheral projection systems from video input to the dome screen.

The system utilized a wide angle lens in each peripheral projector to provide information in the peripheral FOV. The output is a 210 degree (relative to the lens) circular field projected onto the dome surface. Within the optical chain of the peripheral projector, a variable-density (spatial only) filter will be used to provide two functions. The first is the flattening of the field brightness as seen by the pilot. This comparison is required due to lens falloff, light valve falloff, screen gain, and varying bend angles. The second use is the feathering of the peripheral image at the boundary between two peripheral projectors. The roll assembly is used to orient the 4:3 aspect ratio of the light valve within the circular optical FOV.

The light source for the peripheral projector will be provided by a GE light valve projector (PJ7155). The light valve provides a light output of 2,000 lumens with a minimum resolution of 800 by 750 TV lines per picture height resolution.

As mentioned in the foveal projector description, the outside 3 degrees of the foveal image is used to blend/merge the foveal image into the peripheral imagery. The blending is accomplished by electronically feathering that area of the peripheral as a function of angular subtense to the pilot LOS. In addition, the area inside the blend/merge region is electronically blanked within the peripheral to provide a blank hole for insertion of the foveal image.

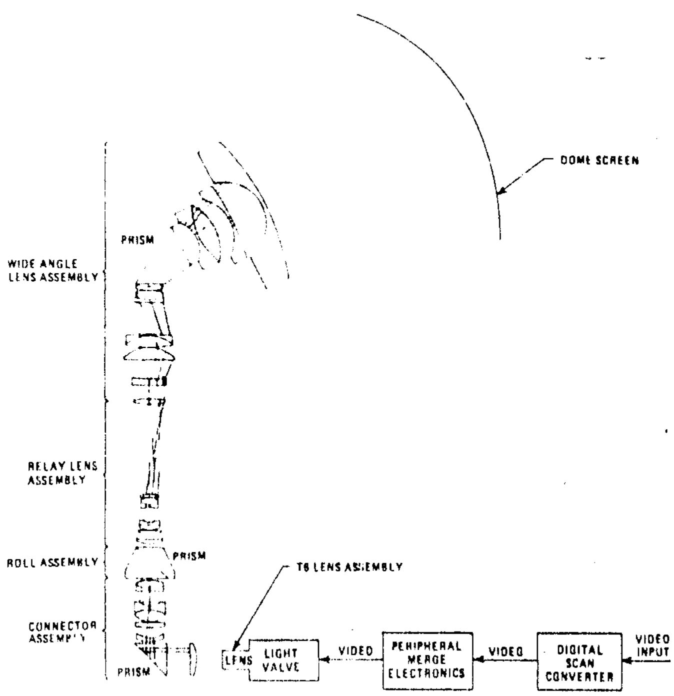

FIGURE 8 Peripheral Projector Diagram

The projection/screen/eyepoint geometry along with the wide-angle lens, would provide a distorted image to the pilot if left uncorrected. TCT utilizes two methods of correction in order to reduce the complexity of the system. The first approach is software mapping within the image generator. This removes the basic distortion introduced due to the projector/eyepoint geometry. The second method of correction is provided by a scan converter. The scan converter compensates for the remaining distortion caused by the wide-angle optics and spherical screen.

HELMET MOUNTED OCULOMETER SYSTEM

The measurement of the pilot's eye LOS utilizes a Helmet-Mounted Oculometer System (HMOS) developed by Honeywell Avionics Division under a sub-contract to Singer. The eye LOS relative to the cockpit is continuously measured by the HMOS in two stages: (1) A standard Honeywell Helmet-Mounted Sight (HMS) measures helmet position and LOS relative to the cockpit, and (2) a recently developed Honeywell Helmet-Mounted Oculometer (HMO) measures eye LOS relative to the helmet. The two LOS are then summed to obtain the eye LOS with respect to the cockpit. The resultant eye LOS and helmet position is then provided to the display computer to control the position of the foveal image. This same data is provided to the CIG for the generation of the foveal and peripheral image. Figure 9 depicts the components mounted on the helmet.

The HMS subsystem utilizes a magnetic field established by a transmitter located behind and above the pilot's head. The magnetic field components are detected by a receiver mounted in the helmet as shown in Figure 9. The amplitudes of the field components are then transformed into helmet position and LOS.

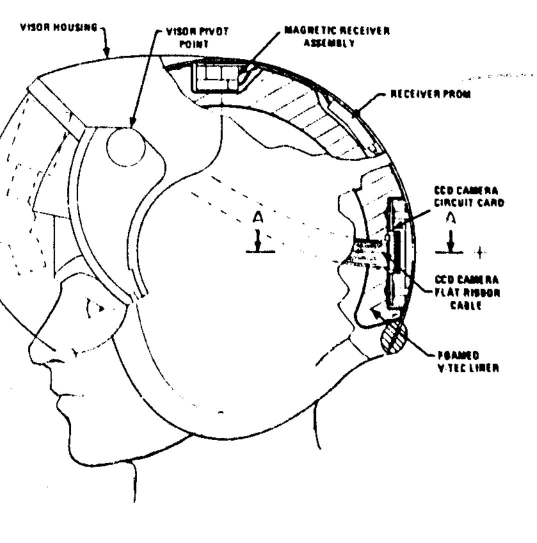

FIGURE 9 Helmet System Layout Mounted Oculometer

The HMO main component is a charge coupled device (CCD) camera that views the pilot's eye from a mounted position on the helmet, Figure 10. The pilot's eye is illuminated by a low intensity IR lamp that shares the same optical path with the camera through a beam splitter. The CCD picks up the illuminator's reflection off of the pilot's cornea along with the pilot's pupil image. Using this information, the HMO system determines the pilot's eye LOS with respect to the helmet. The HMO computational system then combines the HMS helmet LOS with the HMO eye LOS into a combined pilot's eye LOS with respect to the cockpit.

DOME DISPLAY SCREEN

The display screen is constructed of three basic fiberglass panels and rib structures. The panels below the equator are 22.5 degrees x 46.7 degrees; above the equator the panels are 22.5 degrees x 62 degrees; and the cap panels are 22.5 degrees x 28 degrees. The screen finish, a patented Link process, provides a variable gain function in order to provide compensation for brightness falloff due to the projector and observer locations. The screen gain is four above +55 degrees elevation and two below +10 degrees elevation. The gain varies linearly from two to four with elevation angles between +10 degrees and +55 degrees. The dome construction process entails assembling the rib structure then laying in the panels. The panels are riveted and epoxied in place. The seams between panels are filled to the dome radius before the multiprocess screen coating is applied.

COMPUTER IMAGE GENERATOR

A single five channel CIG system drives the four peripheral projectors and four foveal projectors.

Four image channels are continuously projected on the dome screen to provide the peripheral image. The scene content is allocated between channels based upon the eye LOS. The fifth image generator channel is switched between the four foveal projectors as a function of the pilot LOS outside the cockpit. In addition, the foveal image channel is used for the Maverick cockpit display monitor when the pilot's LOS is directed toward the monitor.

The foveal image channel can process 3,000 potentially visible edges at a rate of sixty times a second; the four peripheral image channels can process a total of 6,000 potentially visible edges at a rate of thirty times a second in an instantaneous FOV of 180 degrees x 120 degrees about the pilot's foveal LOS.

STUDIES

During the TCT contract, Singer conducted several studies to define critical system parameters. The test arrangement consisted of viewing a rear projection screen with an eye directed, high resolution AOI in a low resolution background. The image was generated by two television cameras viewing test imagery. One camera operated at full resolution while the second camera was operated at approximately one-fifth resolution. A bench mounted oculometer detected eye position and directed the position of a variable size and blend/merge of the AOI (from the first television camera) inset into the background (from the second camera). A GE light valve then projected the image on the screen for viewing.

The AOI FOV was variable from 10 to 24 degrees. The blend region, within the AOI, was adjustable for zero blend and variable from 1.4 to 6.7 degrees.

In these studies, a blend region of 3 to 4 degrees within the AOI provided the best viewing. With this blend region, the effects of image mismatch, brightness and resolution differences were minimized. A high resolution area of 12 degrees, exclusive of blends, provided the best viewing. This value maybe decreased as the eye tracking accuracy improves. Thus, the final AOI design was a 14 degree FOV of high resolution imagery surrounded by a blending ring of 3 degrees for a total AOI FOV of 20 degrees.

An additional benefit of these studies was the unstructured subjective evaluation of the eye directed AOI concept. As the observer moved his eyes throughout the scene, it did appear to be completely high resolution. However, when the AOI was not eye directed, the difference between AOI and background resolution was easily seen. This provided additional confidence that this concept would be successful.

Prior to the termination of the contract, Singer completed the fabrication and test of the HMOS, Figure 10. Two units were built and both met or exceeded the TCT requirements. In addition, a breadboard of the foveal projector was fabricated but not tested, Figures 11 and 12. This breadboard was tested on a subsequent contract, Project EDIT, described below. These tests indicated that all TCT requirements were met, except for the peak velocity of the azimuth servo requirement. Corrections to this problem have been designed and will be incorporated in the future. The performance of the Singer eye-directed AOI approach is summarized in Table 4.

FIGURE 10 Helmet-Mounted Oculometer System

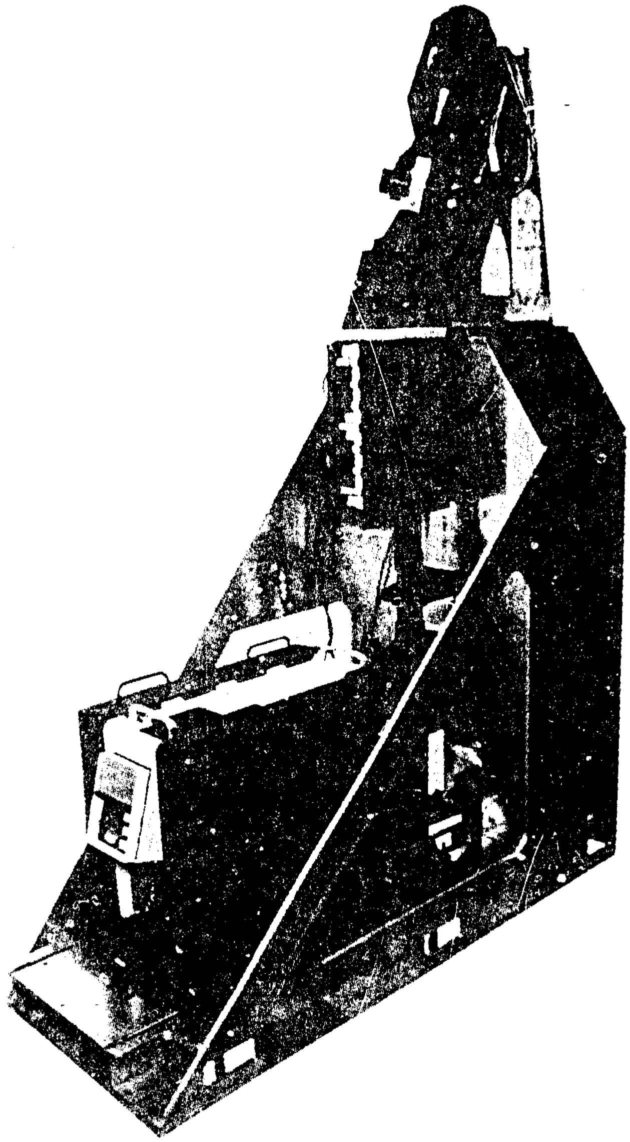

FIGURE 11 Foveal Image Projector

PROJECT EDIT

Project EDIT (Eye-Slaved Display Integration and Test) is a cooperative Air Force and Navy continuation of the Singer eye-directed AOI development started on TCT. The Air Force is providing residual TCT contract equipment and funding. The Navy is providing funds, equipment, facilities, and contract administration. Project EDIT is a multiphased effort which will lead to pilot evaluation of the TCT eye-directed AOI technology on the Visual Technology Research Simulator (VTRS) located at the Naval Training Equipment Center.

Phase I has been recently completed where the HMOS and servos were integrated with the central computer and dynamically tested; and the video electronics checked out and dynamically tested. Phase II started in August 1982. During this phase, all the subsystems will be integrated and tested end-to-end. This will include using an artificial eye to provide known inputs to the HMOS and measuring the response of the projector servos. Preliminary plans are that Phase III will integrate the breadboard eye-directed AOI equipment on the VTRS for pilot evaluation. The exact plan and schedule for Phase III will depend upon available funding and success during the various stages of integration.

The Air Force goal for Project EDIT is to determine the feasibility of the eye-directed AOI concept for tactical combat training. If successful, data from Project EDIT will be used to establish system performance specifications for future procurements. The eye-directed AOI approach has the potential of meeting most of the tactical training requirements.

CONCLUSIONS

Although the TCT contracts were terminated, several developments were successfully completed, such as the 36-inch metal funnel CRT and the Helmet Mounted Oculometer System. These equipments are currently being used in laboratories

TABLE 4 SINGER TCT PERFORMANCE PARAMETERS

Field of View:	Total aircraft FOV including head motion
Resolution:	1.4 arc minutes
Contrast Ratio:	14:1
Brightness:	1.5 foot Lamberts
Foveal FOV:	20 degrees diameter with 3 degrees merge
Peripheral FOV:	360 degrees H, +90 degrees, -60 degrees V except where occulted by cockpit
Number of Edges:	1 foveal channel, 3,000 edges @ 60 Hz 4 peripheral channels, 6,000 edges @ 30 Hz
Texture:	Surface (16 unique patterns)
Moving Model Types:	Airborne, 10; Ground, 50
Environment:	Full weather, time of day effects
Gaming Area:	1,000 x 1,000 nautical miles
Scene Enhancement:	Articulated parts, light point features
Visual Data Base:	Transformed DMA, Hand modelled .
Special Effects:	Head Motion Compensation G-Dimming

to perform much needed research. In addition, the feasibility of other developments were demonstrated such as the inset mini-raster on a CRT and the foveal projector. It is hoped that work will continue to complete and evaluate these developments.

On the TCT program, there was a continuing evaluation of the Technical and Training Risks of fielding a successful WST. It is our belief that the work accomplished on these contracts and described in this paper have significantly reduced the Technical Risk of these two approaches. However, continued effort is needed to reduce these Technical Risks for a production procurement. Additionally, the Training Risks have not been significantly reduced. A simulator environment for flying combat tasks is needed to permit task-loading the pilot to predict the training performance of the visual system. Continued efforts, such as Project EDIT and other similar work, are needed to reduce the Training Risks.

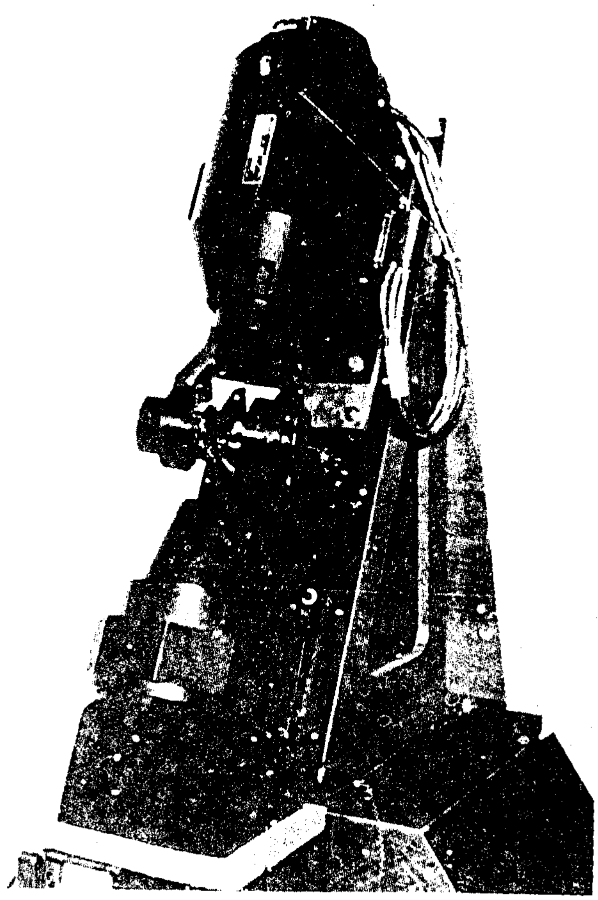

FIGURE 12 Closeup of Azimuth/Elevation Servo Assembly

Another contribution of the TCT program, although not strictly technical, is demonstrating the importance of thoroughly communicating to the design engineers the pilot's tasks, visual references and how such visual references are used. The Air Force, General Electric and Singer-Link agree that the orientation trips and the continued dialogue between designers and pilots during the TCT program was extremely useful in designing the TCT system and determining design and performance tradeoffs. It is hoped that these effective communication techniques will be used on future programs.

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DATA BASE GENERATION SYSTEM FOR COMPUTER GENERATED IMAGES AND DIGITAL RADAR LANDMASS SIMULATION SYSTEMS.

By Lt. Col. Manfred Haas,
Diether Elflein and Peter Gueldenpfennig

ABSTRACT

The paper deals with a semi-automatic, interactive system to generate data bases from Digital Landmass System (DLMS) Data, for Computer Generated Image Visual Systems (CGIVS) and for Digital Radar Landmass Simulation (DRLMS) Systems.

Terrain information and certain culture features can be gained from DLMS data automatically for CGIVS and DLRMS data bases. Additional information is prepared by interactive methods, including the use of model library for CGI data bases developed by batch procedures. Data bases can also be developed solely by batch procedures.

INTRODUCTION

In 1975 the German Airforce and Navy decided to use a Computer Generated Image Visual System (CGIVS) and a Digital Radar Landmass Simulation (DRLMS) System for the TORNADO Operational Flight Training and Tactics Simulator. The development of the prototype CGIVS demonstrated that in order to fullfill the operational requirements for this type of simulator, a substantial increase in scene content would be necessary. Therefore, the CGIVS production units have a much higher data processing capability than the prototype. Table 1 shows a comparison of the capabilities of the prototype CGIVS and production units.

	PROTOTYPE CGIVS	PRODUCTIONS CGIVS
EDGES/SCENE	2000	8000
POINTLIGHTS/SCENE	1000	4000
FACES/SCENE	500	4000
REAL TIME DATA BASE CAPACITY	10.000	40.000* Plus Dynamic Reloading
TV LINES	525	875
RASTER ELEMENTS/TV LINE	512	1000
TEXTURING	NO	YES
CURVED SURFACE SHADING	NO	YES

Table 1

Comparison of Prototype and Production CGIVS for the Training Simulator TORNADO

The increased scene content for the new CGIVS had substantial impact on data base generation. For the prototype system, the CGIVS data bases had been generated manually by batch operation. The areas and models had been derived from geodatic charts, areal photographs, blue prints, and normal photographs. The scene content of this material was reduced and manually transformed into graphic vectors. The coordinates of the vertices of the edges were defined on punched cards. Only after the coordinates of the vertices had been defined on the punched cards automatic data processing could be used for operations such as reading-in, testing, scaling and computing of face normals and seperation planes.

The high information density of the data bases for the new CGIVS led to the necessity for use of automatic and interactive procedures for the development of data bases. For this new CGIVS, Messerschmitt Bolkow-Blohm (MBB), designed the Data Base Generation System (DBGS). This DBGS will not only be used for the design of data bases for CGIVS, it will also perform generation and modification of data bases for the DRLMS system. It is worth mentioning that all DRLMS for the German and Italian TORNADO simulators have an update console with which small modifications to the data bases can be performed. One system out of the six ordered by the German Government and one of the Italian Airforce systems has additional computer peripherals used to transform source material into online data bases. The source material for this transformation program is cartographic information in digital form in accordance with the product specification for Digital Landmass System (DLMS) Data Base/ICD/100 1. Edition, July 1977.

DEVELOPMENT OF VISUAL DIGITAL DATA BASES

Structure of The Visual Data Bases

The data base for the CGIVS represents the mathematical description of the stylized world. This description is in coded form on a storage medium, so that the CGIVS can read it out in an online process and can perform further data processing tasks.

The geometry of the "world" is defined by points, lines and faces. A point is defined by storage of its X-, Y-, and Z-coordinates. Two points define a line. By the use of several lines a closed polygon can be developed which represents a face. The CGIVS shows points and faces which are described not only by their geometrical position, but by other attributes like color, texturing, or curved surface shading.

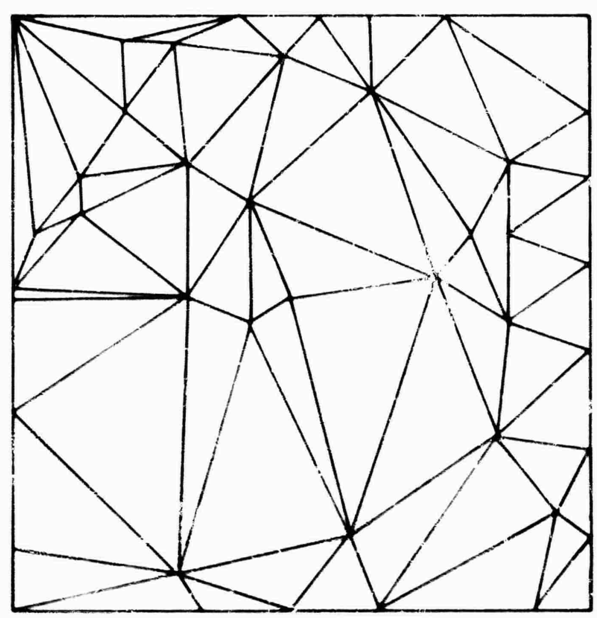

Figure 1. Terrain Approximation

The morphology of the terrain is approximated by triangles. (See figure 1.) Outlines and position of the triangles are matched to the terrain in an optimum manner. The number of triangles, and therefore the information density of the data base, is a function of the roughness of the terrain. This means that the information density of a planar landscape is relatively small, and for mountainous terrain, it is very large.

It is possible to divide these triangles into more faces, in order to show changes of ground vegetation and culture features by the means of different attributes.

Three-dimensional objects can be built out of these faces. These objects, in turn, form more complex models. Objects are always convex, while models can also have a concave character. Objects and models can represent houses, towers, bridges etc., which are positioned in the terrain.

In principle the DBGS enables three methods of data base generation: Automatic transformation, interaction and batch (See figure 2).

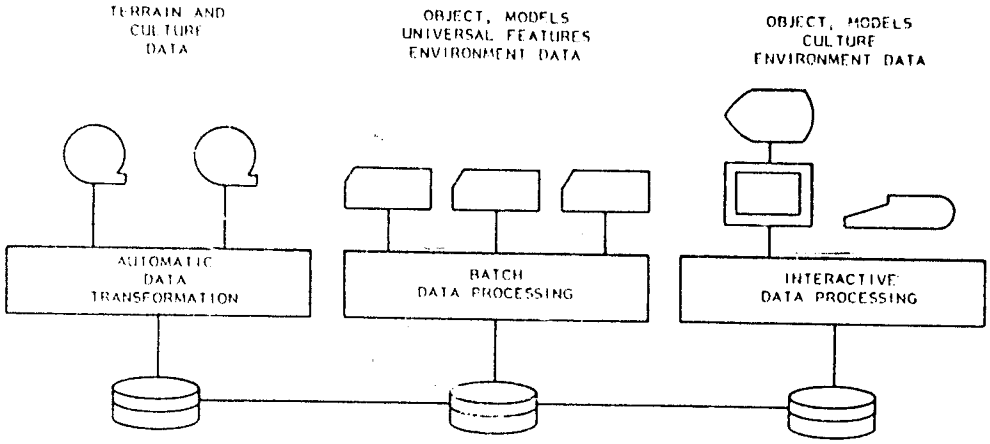

Figure 2. Data Base Generation System

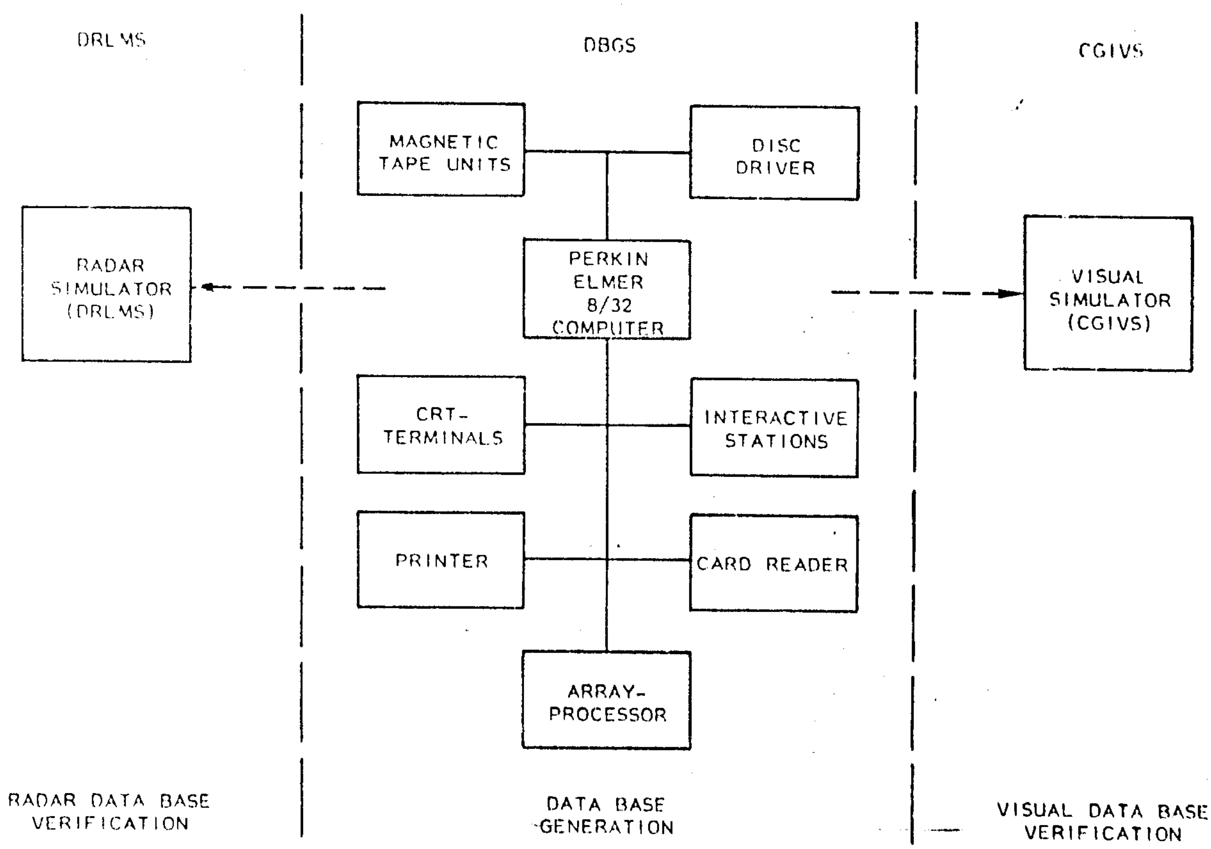

Figure 3. Hardware Configuration

Hardware Configuration (See figure 3)

The Data Base Generation System is a stand-alone computer complex with computer peripherals. It can be operated independently from the simulator and consists of three main groups: Computer System, Display System, and Interaction System. Only commercial hardware is used. The system has the following configuration:

a. One Perkin Elmer 8/32 Minicomputer with 1 MB Functional Storage, Writable Control Store and Floating Point Unit.

b. One type AP 120b Array Processor developed by Floating Point for parallel performance of time comsuming procedures.

c. Two Perkin Elmer Type 550 CRT terminals which enable simultaneous communication with the compute

d. One card reader (1000 CPU) and one line printer (300 LPM), developed by Perkin Elmer as additional input/output peripherals.

e. Two 9-track, 1600 bpi mag-tape units for the input of large amounts of data.

f. Three magnetic 300 MB disc drives for the storage of completed data bases.

g. Two interactive stations, each consisting of one Tektronix 4014-1 graphics terminal, and one Tektronix 4954 digitizing tablet for parallel graphical data processing. The picture content of one graphics terminal can be documented using one Tektronix 4631 hard-copy unit.

This hardware configuration enables the transformation of DMA data, interactive data base generation and modification, as well as batch processing for the generation and modification of data bases for CGIVS and for DRLMS.

VISUAL SIMULATION SYSTEM/DATA BASE GENERATION

Data Base Sources

The source material for the Data Base Generation System is digital landmass data. To satisfy the tremendous requirment for such data, the military geographical agencies of the NATO-countries have defined one standardized format in which the information on geographical charts is digitally stored.

There are two types of DLMS data: terrain data and culture data. This information for the same area is stored on two different magnetic tapes. The terrain data represent altitude data at the cross-points of a grid system. The grid systems are divided into five different zones according to latitude, so that each square has an edge length of 100 meters for the coarser level of detail (level 1), and 30 meters for the finer level of detail (level 2).

The culture data describes the natural terrain structure and the artificial cultural features of the terrain. There are points, lines, and faces defined, which are numbered by an analysis code. Information concerning the geographical position and dimension, as well as the material category and the identification code, is attached. Thirteen different material categories represent, for example, water, earth, rock, metal, etc. By the use of the identification code, characteristics can be differentiated in very great detail. For example, different shapes of roofs or bridges can be discerned.

Terrain Transformation

An algorithm is used in the Data Base Generation System which enables the triangulation of DLMS terrain data in a way that the advantage of variable information density can be used. The logic of this algorithm is based primarily on "trial" and "error". The trials are performed for a certain number of DRLMS grid-points, for which the standard deviation and maximum error in comparison with the triangulated terrain is computed and is compared with defined maximum values.

Culture Transformation

The DLMS face characteristics are projected on the triangulated terrain so that a face subdivision is performed. The attributes of these faces can be gained from the information on the material category and the identification code. For point features, only the positions will be transmitted during transformation. During the interaction it must be decided whether a line feature describes, for example, a river such that a long stretched face has to be projected into the terrain, or only a bridge has to be shown, which is called up from the model library.

Further data on texturing and curved shading are allocated interactively.

Interaction

In order to correct the deficiencies in the digital source material and those which have been introduced during the transformation program, it is necessary to perform interaction during the different phases of the data base generation. One starts with non-digital source material, as for example geodetic charts, air-photographs, etc. The information of those data mediums are brought into the data bases by use of the interactive station.

The hardware of the interactive station consists of a graphics terminal, a digitizing tablet, and a hard-copy unit. The source material is positioned on the digitizing tablet and is scanned by means of a digitizer. The digitizing process is traced on the graphics display. A cursor defines the position of the digitizer unit. With a menue attached to the digitizing tablet, or by means of the alphanumeric keyboard of the graphics terminal, additional information can be put in. The interactive station is supported by a complex software package which allows one to select certain data as well as to change or input new data. This software package limits the menue effort to a minimum and is user friendly.

Correction of DLMS-data

Before the transformation process starts, it has to be ensured that the available DLMS data are in accordance with the convention of the DLMS specifications. Experience has shown that the number of errors which have to be corrected interactively varies according to the care with which the data was collected. In this phase, single characterstics can be changed or completely new characterstics can be added to the DLMS format.

Correction of the Online Data Bases

All necessary information which can not be gained from the DLMS data bases must be added interactively after the transformation has been performed. These are primarily the lines of communication which, to a certain extent, are not existent in the DLMS data bases. Further data on new faces or models has to be added where the transformation program shows only non-identified lines or point features. Additionally, more models can be superimposed. Finally at this stage, interaction is necessary in order to allocate specific attributes such as color, texturing, or curved surface shading as well as the creation of universal features.

Generation of three-dimensional Objects and Models

For the model library a complex store of objects and models is created. This is necessary in order to describe the different culture features in the terrain. The basic forms of simple objects are read-in on the digitizing tablets from construction drawings. These objects can be varied by simple geometrical operations like scaling, mirror inversion, rotation, etc. Complex models can be built up interactively from different objects. The German Airforce and Navy require a complex model library. The models include a drilling platform, mine shaft superstructure, chemical plant, coke plant, refinery, transformer yard, processing industries with different shapes of roofs, scrap yard, rotating cranes, railway stations, different types of bridges, open-ended stadiums, family houses, castles, residences, hospitals, different types of church towers, airport control tower, runways, aircraft parking areas, taxi ways, drydocks, navigation light ship, light houses, etc.

Data Base Verification

The completed data bases are demonstrated on the graphics display of the Data Base Generation System. The geometrical construction of the data bases can be evaluated. However, all attributes are only numerically indicated (code tables). In order to get a complete impression of the data bases with respect to texturing, curved surface shading, color and the three-dimensional relationships, it is necessary to demonstrate them on an actual CGIVS. By performing this verification, the data base will also be evaluated with respect to the dynamic appearance. The verification might result in the need for corrections, which can be accomplished in one of the above mentioned steps.

Verification of data bases on the real CGIVS is now used only temporarily. In order to prevent use of the simultors at the squadrons for data base generation, it is planned to extend the Data Base Generation System by adding a non-real-time Computer Generated Image System.

German Data Base Visual Requirements

For the time being the German Airforce and Navy require the following complete data bases:

a. Navigational area of upper Bavaria, including an airforce base and a NATO-standard bombing range

b. Sea area with a coastline

c. Seaport

d. Complex model library - The generation of simple objects and models has been mentioned before. More complex models to be designed are:

- Fighter aircraft
- Transport aircraft
- Tanker aircraft
- Typical kinds of ships
- Ground vehicle (heavy)
- Ground vehicle (medium heavy)

By the mid 1980's the German Airforce and Navy will create their own data bases in a common data base generation center using the equipment here described.

RADAR SIMULATION SYSTEM DATA BASE GENERATION

The Data Base Generation System also makes it possible to generate data bases for the Digital Radar Landmass Simulation (DRLMS) System. In order to gain a DRLMS data base, a transformation of United States Defense Mapping Agency (DMA) source data is performed. The system allows interactive modification of the DMA data bases or the generation of new data bases from topographic charts. The same hardware is used for generation of both the radar and visual data bases. Verification of completed data bases is performed on an actual DLRMS, at least for the time being.

Automatic Transformation

The on-line DRLMS data bases are produced from the source material by means of a translator program wherein the grid format is automatically transformed into a compressed vector format. The translator program consists of two parts: the terrain transformation and the culture transformation. Both processes are performed separately and the information is later combined to achieve the on-line DRLMS data bases. The transformation program uses a variable compression technique with the following characteristics:

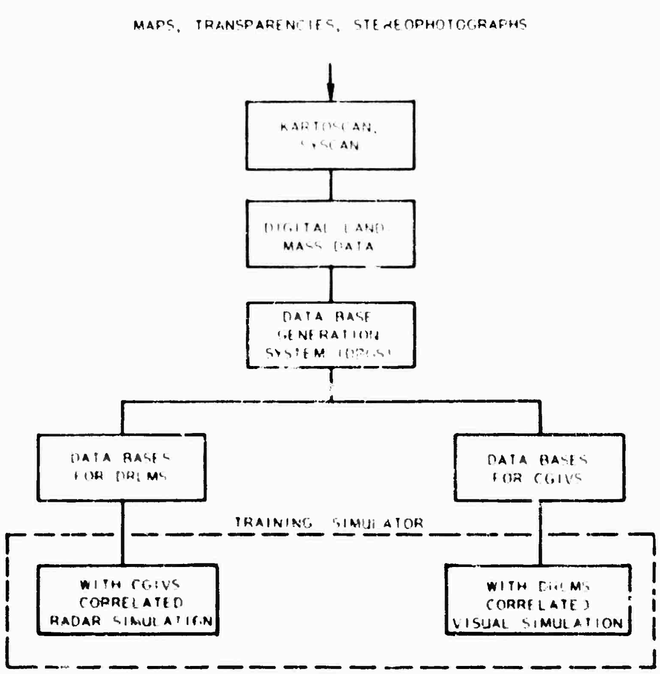

Figure 4. Generation of Data Bases for Training Simulators

The terrain is approximated by plane faces which are constructed with lines (vectors). One vector indicates a change in the elevation. The number of vectors which are necessary to model a given terrain is dependent on the roughness of the terrain and the required accuracy of the image.

Isolated objects such as towers and power pylons are defined as point targets. Point targets can be identified by their radius, their height above ground, and by their directional or nondirectional reflectivity characteristics.

Characteristics with length dimension (e.g., bridges, streets, etc.) are defined by line segments. Height above ground and reflectivity data can be added.

Large area features like lakes, irregularly shaped buildings, etc., can be defined by multiple line features. Height and reflectivity data are added. Each data point that is stored includes information concerning position and height in respect to the foregoing value. Therefore all of these values can be defined as vectors. In comparison to code techniques with constant grid distance, the variable compression technique results in a substantial saving of storage capacity. This allows a much better and more realistic image in systems of comparable storage capacity.

Interactive Data Base Modification

After having performed the first step of transformation, the data base can be improved interactively. In addition, there is the possibility of modifying existing data bases by subtracting or adding parts or changing the reflectivity. Dimensional characteristics can be added and features can be changed in respect to length, width and height.

Interactive Data Base Generation

An additional program of the DBGS allows data base generation without using Defense Mapping Agency Data. Interactively generated terrain data are formatted in a way that they are compatible with data received from the automatic transformation program. In addition, interactive generation and formatting of culture feature data can be performed.

Verification and Requirements for Radar Data Bases

The data bases gained from the DBGS process can be verified by means of the actual DRLMS. The same applies for modified radar data bases. Using the DRLMS, the realistic dynamic appearance is evaluated. However, in order to use the actual DRLMS only for training purposes, the Data Base Generation System will be extended by computer peripherals so that the verification process can be performed with the Data Base Generation System.

At present, a realtime DLMS data base is required for upper Bavaria.

Visual and Radar Data Base Correlation

Visual data bases as well as radar data bases are developed by industry with the assistance of the user. Figure 4 shows the data base generation for CGIVS and DRLMS systems. By using identical source material, correlation of the displays for both simulation systems is possible.

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ANALYSIS OF FIDELITY REQUIREMENTS FOR SIMULATED ELECTRONIC MAINTENANCE TRAINING EQUIPMENT

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ABSTRACT

Maintenance training simulators have proven to afford equal or superior training at a lower life cycle cost than actual equipment trainers when teaching troubleshooting based on front panel indications, failure symptoms and some in-drawer visual indicators. The purpose of the study was to determine the effects of two-dimensional and three-dimensional fidelity of simulation and three levels of reduced accessibility to test points during training, on student troubleshooting performance while locating faults at the component level. A total of 186 students were observed and tested in the ET Splice modules of a Navy Basic Electricity and Electronics course. Conclusions are drawn about the relative training effectiveness of simulated and actual boards and recommendations are made in selecting active test points on simulated printed circuit boards.

INTRODUCTION

Over the last few years, computer simulation maintenance trainers have made significant inroads against actual equipment trainers (AET's) in hands-on electronic maintenance training. Simulators have proven to provide equal or superior training at a lower life cycle cost when teaching troubleshooting based on front panel indications, failure symptoms and some in-drawer visual indicators.

However, in the area of hands-on troubleshooting to the component level, the relative cost-effectiveness of AET's versus simulation trainers is not clearly understood. Actual equipment trainers are a higher fidelity simulation of the field equipment and theoretically should provide better transfer of training. However, high AET purchase costs and lower reliability leads to high life cycle costs. Trainers generally have a lower life cycle cost, but these savings are accompanied by a reduced fidelity of simulation; especially a reduced number of test points. Simulation engineers indicate that if all test points on a circuit board (50-100 points) are simulated, the complexity of modeling the correct test equipment readings for each failure at every point becomes prohibitive.

Another difference between AET's and simulation trainers is that trainers may utilize a photograph of a circuit board with test points available in appropriate locations. The training effects of this reduced fidelity of simulation have not yet been determined.

The general assumption is that AET is more costly and effective in training for troubleshooting to the component level, while simulation trainers are less expensive and less effective due to the limited number of test points and reduced visual fidelity. The question is which one is more cost-effective. Engineers can estimate the cost of a trainer for various numbers of simulated test points and visual representation based on previous experience. The question remains as to the relative effectiveness of a trainer depending on the fidelity of simulation and number of test points simulated. The purpose of this study was to determine the transfer of training to actual equipment derived from training on modified printed circuit boards with varying numbers of simulated test points represented photographically and in three dimensions.

METHOD

Initial Data Acquisition

Initial data were collected to determine the points most frequently probed by Basic Electricity and Electronics (BE&E) students. These initial data were required in order to select the points to be exposed during the experimental phase of the study.

Students were categorized as high, medium and low proficiency levels based on prerequisite course completion time. Trainees were observed during normal coursework and troubleshooting lessons. No changes were made in the current curriculum except for the additional troubleshooting session at the researcher's table. The observation of troubleshooting behavior resulted in the following data:

1) number of trainees probing each test point

2) sequential order of probes.

Apparatus

Subjects in the experimental study were tested using modified actual equipment in order to eliminate the expense of creating a software package to control specialized hardware. Printed circuit boards normally used in the trainer were modified to control access to test points. This modification was based on test points probed during the initial data acquisition.

Potential test points were created by soldering a short copper wire to the test point. Then the boards were sprayed with clear varnish to place an insulating coat over the entire board. Test points were made accessible by cutting away the coating on the end of the wire. By cutting away the varnish on different numbers of potential test points, experimental groups of test subjects were trained with varying numbers of accessible test points for hands-on practice. The test points made accessible matched those probed by 33%, 67% and 100% of the trainees in the initial data gathering phase. The board modification in Figure 1 simulates the effect of varying numbers of accessible test points on a high fidelity, three-dimension simulation of a PC board.

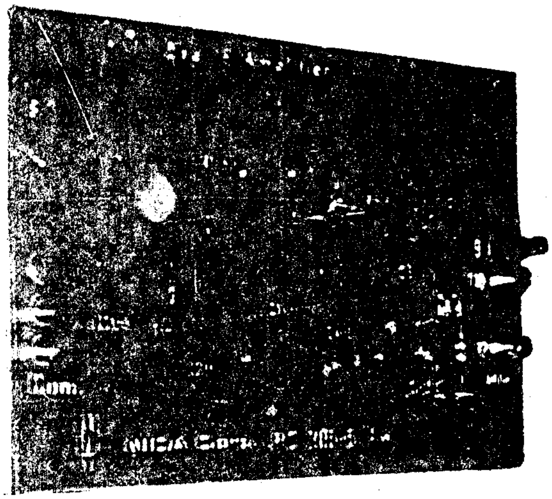

Figure 1 Three-Dimensional Simulation

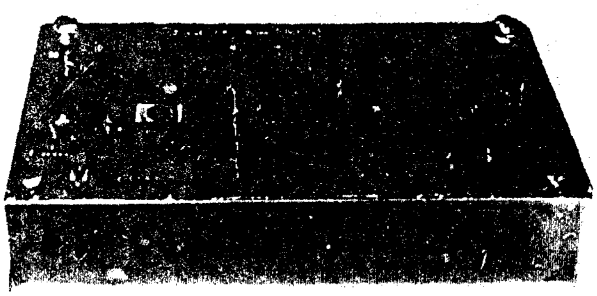

Figure 2 Two-Dimensional Simulation

The board modification in Figure 2 simulates the effect of varying numbers of test points on a photographic simulation of a PC board. A photograph of the PC board was mounted over the actual board. Test points were created by placing a hole in the photograph, projecting the copper wire through, and coating it with varnish. Test points were then made accessible by cutting away the coating in the same manner as above.

Table 1 indicates the number of test points made accessible on the FM Radio Second IF Amplifier Board. Faults were grouped together such that the required minimum probe points would have a 90% overlap. The ratio between accessible points and the minimum number of points required was 4.50:1 for 100% accessibility, 2.75:1 for 67% accessibility, and 1.60:1 for 33% accessibility.

Table 1

Test Point Accessibility
FM 2nd/IF Amplifier Board

Fault Group	Fault	Minimum Tests Required*	Test Points Accessible 100%	67%	33%
1	Diode Open, Resistor Open	7	42	22	12
2	Resistor Open, Resistor Open	11	42	28	17
3	Transistor Short, Open Run	11	41	28	17

*NOTE: Using Half-Split Technique

Subjects

Test subjects were trainees in the ET Splice modules of a Navy BE&E course. A total of 186 trainees were included in data collection.

Experimental Design

A two-way analysis of variance design (see Figure 2) was used for the main independent variables of fidelity (actual boards vs photographic boards) and three levels of test point availability (100%, 67%, 33%), with a control group (unmodified boards).

Three different circuit boards were utilized in the study; an FM Radio First IF Amplifier board, FM Radio Second IF Amplifier board and a Power Supply board. Each had three fault group types. Trainee proficiency levels were matched for each treatment condition. The dependent variables were number of test points probed, time to probe, and number of trips to the learning supervisor before fault localization. In addition to the main experimental effects, the troubleshooting logic used by trainees was examined. The logic was examined for differences by experimental treatment, as well as analysis of what types of strategies were used most consistently and effectively.

		Fidelity	
		Three Dimensional	Two Dimensional
Test Points Exposed	100%	*	
	67%		
	33%		
	Contr.		

*Each cell balanced with 3 levels of proficiency and 3 fault groups.

Figure 3 Experimental Design

Procedures

When the subject trainees were ready for a practice session on one of the boards used in the study, they were assigned to the research station. The experimenter gave the trainee a pre-faulted board modified to one of the seven treatment conditions. Subjects proceeded to troubleshoot the board and take their exercise sheets to the school's learning supervisor for grading. This step was repeated with an identical board and treatment condition, but a different fault. When the learning supervisor determined the subject had mastered the board, the trainee was given an unmodified board to troubleshoot. This test was the criterion performance to measure transfer of training to actual equipment after practice on modified boards.

During the troubleshooting of both modified and unmodified boards, the experimenter recorded: the number of probes, probing time, subject comments and all other applicable data. These data were then analyzed to determine the training effects of simulation fidelity and test point availability on troubleshooting behavior using actual equipment.

RESULTS

Probes and Time

At the time this paper was prepared, analyses were completed for the FM Radio Second IF Amplifier board only. Results for the other boards will be reported at a later date.

The primary measures of effectiveness were number of probes and time required to locate the fault. Figure 4 exhibits the effects of percent points available, fidelity and student proficiency level on these two measures during criterion tests on actual equipment.

Students tended to probe fewer times and locate the fault in less time when trained on the board with 67% of the points accessible. However, this difference was not statistically significant. Students tended to probe fewer times and locate the fault in less time when trained on unmodified boards as opposed to 2D

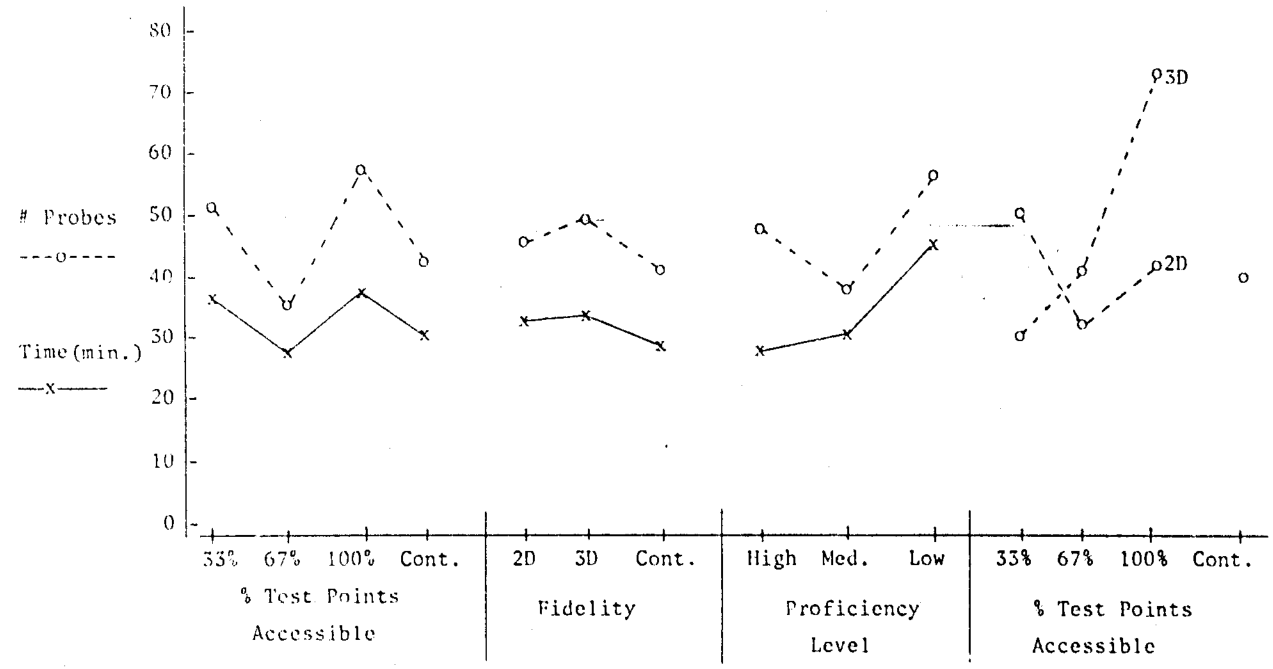

Figure 4 Probes and Time By Experimental Condition

and 3D boards. This difference was not statistically significant. High proficiency students located the fault in significantly less time ($p=0.056$), but number of probes was not significantly affected by proficiency.

There was a significant interaction ($p=0.01$) between fidelity of simulation and percent points accessible during training on number of probes in testing. Students trained on two-dimensional boards with 67% of the points accessible had the fewest number of probes in testing.

Troubleshooting Success

A Chi Square Analysis of student troubleshooting success (see Table 2) found no significant difference ($p=0.17$) in fault diagnosis success rate between students trained on two-dimensional, three-dimensional and unmodified boards. There was also no significant difference ($p=0.59$) between students trained on unmodified boards and those trained with 33%, 67% and 100% test point accessibility.

Table 2

Fault Location Success Rate By Board Type In Training

	Correct First Time Yes	Correct First Time No		Correct First Time Yes	Correct First Time No
2D	19	10	33%	12	5
3D	11	16	67%	10	11
Control	4	3	100%	8	10
			Control	4	3

Troubleshooting Logic

The specific points probed by students during performance tests were analyzed in order to provide guidance to engineers in selecting which points students are most likely to probe. Analyses addressed troubleshooting logic and characteristics of points probed.

The sequences of probes for each of the performance tests were analyzed to determine which troubleshooting strategies were utilized by the students. Results appear in Table 3. Definitions of these strategies are:

Half-Split	Testing the midpoint between good and bad signal until fault located
Linear I/O	Testing output of each circuit
Linear Tracing	Testing components sequentially until faulty signal found
Reliability Testing	Testing least reliable untested component
Symptomatic	Testing based on equipment symptoms
Random	No logical sequence of tests
Combination	Use of two or more strategies

Since the dominant strategy is random probes, no rules can be recommended for selecting active test points based on troubleshooting strategy.

Table 3

Troubleshooting Strategies Utilized

Strategy	Times Utilized
Half-Split	1
Linear I/O	6
Linear Tracing	2
Reliability Testing	5
Symptomatic	3
Random	25
Combination	18

An analysis of characteristics of the printed circuit board components tested by students was conducted in order to determine whether the characteristics of components affect the frequency with which they are probed. Table 4 contains the results of this analysis.

Table 4

Test Point Probes By Component Characteristics Expected Versus Observed Frequency

Characteristic	Type	Expected Probes	Observed Probes	Difference (%)
Electronic Location	Input	201	125	-38
	Middle	100	210	+101
	Output	297	346	+16
	Other	3583	3509	-2
Electronic Circuit Location	Input	498	458	-8
	Middle	100	201	+101

Table 4
(Cont'd)
Test Point Probes
By Component Characteristics
Expected Versus Observed Frequency

Characteristic	Type	Expected Probes	Observed Probes	Difference (%)
	Output	498	462	-7
	Other	3085	3060	-.8
Physical Location	Edge	1793	2025	+13
	Middle	297	514	+73
	Other	2091	1642	-21
Size	Large	698	970	+38
	Small	3483	3211	-7

If students test components without regard to their characteristics, then the expected proportion of probes associated with each component will be equal to the proportion of test points associated with that type of component. A Chi Square Analysis of expected versus observed probe frequency found the differences to be significant ($p > 0.01$) for all component characteristics.

Students test the midpoint in the board circuitry as the first step in a half-split technique, but they do not continue this procedure until the faulty component is located. The board output is tested more often than the input. The physical midpoint was near the electronic midpoint and shows the same trends.

Once a circuit on the board is suspected of being faulty, the student predominantly probes the midpoint of the circuit, as opposed to the input or output. Finally, students are more likely to test a large component than a small one.

CONCLUSIONS

Basic electronics training on circuit boards with reduced physical fidelity and reduced test point accessibility is equal to or superior to training on unmodified actual circuit boards. Students trained on two-dimensional boards with 2.75 times as many test points available as required had the best overall troubleshooting performance during testing.

Other than the minimum points specifically required to detect a fault, the following points should be accessible on a simulated board:

- Electronic Midpoint of Board
- Board Outputs
- Electronic Midpoint of Circuit
- Test Points Associated With Large Components

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THE INTEGRATION OF VIDEODISC, CAI, AND 3D SIMULATION FOR SKILLS TRAINING

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ABSTRACT

Training in maintenance skills has become increasingly more important as the cost of replacement parts and experditures for maintenance personnel have risen. More effective and efficient skills training has been identified as a means to limit costs through fewer false repairs, shorter down time, and decreased numbers of personnel required for maintenance. Advocates have championed various systems and devices for this training, to include in different forms, actual equipment, flat panel simulators, three-dimensional simulators, videodisc, and computer assisted instruction. This paper discusses the integration of interactive videodisc, computer generated images, and three-dimensional simulation in a total system concept for maintenance skills training. Different types of maintenance skills are identified, along with the methods and techniques for training those skills. Implementation of the methods and techniques in an integrated system is presented, to include the means for providing modeling, drill and practice, cueing and prompting, feedback, and evaluation. Two different systems are identified, rationale for the differences is provided, and the advantages each has in intended use is specified.

INTRODUCTION

The training of maintenance personnel has always been of critical importance. Training problems have become even more acute in the recent era of runaway technological advances that has resulted in increasingly complex equipment. Additionally, the costs of replacement parts and expenditures for maintenance personnel have risen. Of particular concern to those involved in maintenance training is the teaching of effective and efficient troubleshooting, as a means of limiting costs through fewer false repairs, shorter down time, and decreased numbers of maintenance personnel. In a time of decreasing training budgets that necessitate shorter maintenance training courses and increasing student/instructor ratios, it is imperative that the methods and media used for training be maximally effective.

This paper addresses the some of the difficulties associated with maintenance training. It first addresses the types of skills required of the maintenance technician. It then discusses maintenance training from the standpoint of the learning curve and talks to the media and methods that have traditionally been used to teach the trainee at each stage of learning. Finally, it discusses the use of an integrated system concept, made possible by recent technological advances. This technology has been applied to maintenance training, and this paper describes two systems that have been developed to apply the concept.

MAINTENANCE SKILLS

Equipment maintenance requires a diversity of skills, which range from simple tasks such as rotating a switch to very difficult tasks such as interpreting and following schematics in the process of tracing signal paths. Both cognitive and psychomotor behaviors are required of the maintenance technician to perform these tasks. Table 1 illustrates some of these behaviors.

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TABLE 1
Sample Maintenance Behaviors, Missile Maintenance
(Adapted from AMTESS Phase 1 Final Report)[1]

It is evident that there are many enabling skills and knowledges that the trainee must have before he begins to acquire the specific maintenance skills listed in the table. The enabling skills include such things as terminology, component locations, functional system knowledge, use of technical materials, and basic electronics. An effective and efficient maintenance technician must possess both of these types of skills.

MAINTENANCE TRAINING

The training of maintenance skills has been a difficult proposition. From the standpoint of a training system, the student must be taught each of the many types of maintenance skills. Each type of skill must be taught in a way that is consistent with its nature. In addition, the synergistic nature of the maintenance environment requires that the student be taught to use all of these skills as an integrated whole.

Learning Stages

The acquisition of knowledge is almost always a gradual process. As Myers[2] notes, the classical learning curve can be divided into three learning stages: acquisition, consolidation, and evaluation. In the acquisition stage, the student gains an initial familiarity with the subject matter. In the consolidation stage, he gains criterion competency. His ability to perform is tested in the evaluation phase, and administrative decisions are made on the basis of his performance.

The application of this staged process in maintenance training is clear. The student should first be guided in the acquisition of basic knowledge and skills using techniques that are appropriate for this type of learning. This is followed by practice that requires the use of these skills in a realistic manner. The cues, prompts, helps, and remediation used during this practice should gradually be reduced until the student is able to perform at a criterion level using only the materials which will be available to him on the job.

In looking at equipment maintenance holistically, it appears that the acquisition stage addresses the enabling skills and knowledge discussed above. These skills and knowledges are primarily cognitive in nature, though they are certain to include some psychomotor elements as well. These types of behavior can usually be taught using low fidelity representations such as textual descriptions, line drawings, photographs, motion pictures and other two-dimensional media.

During the evaluation stage, the student must be able to perform complex cognitive and psychomotor behaviors. The emphasis in this stage is on the student's psychomotor activities, since his cognitive processes are normally manifested in his actions. Thus, testing the student's ability requires the use of some higher fidelity three-dimensional medium, such as actual equipment or a simulator.

The consolidation stage provides a transition between the primarily cognitive acquisition stage and the primarily psychomotor evaluation stage. Although the student learns about maintenance in the acquisition stage, it is in the consolidation stage that he actually learns to do maintenance. It is here that he will gain knowledge of the synergistic aspects of the job he is to perform. The gradual fading of cues, prompts, etc., inherent in this stage, necessitates the concurrent use of both low fidelity two-dimensional media and high fidelity three-dimensional media.

Methods and Techniques

Various methods and techniques have proved to facilitate training of maintenance skills. Media selected for training must be capable of incorporating these training aids. Examples include guided practice, modeling followed by immediate application, and realistic representations of malfunctioning equipment. In addition, those proven methods and techniques common to all successful training should be available. This would include capabilities such as self-pacing, remediation, cueing and prompting, and branching.

TRADITIONAL TRAINING MEDIA

Media traditionally used for maintenance training have met the requirements of the three stages of maintenance training with varying degrees of success. Successful training has occurred when well-designed instruction has been delivered using media appropriate for the learning stage in which they have been used. Print and other two-dimensional media have been successfully employed most often when used in the acquisiton stage. Actual equipment and three-dimensional simulators have been successfully used for evaluation. Appropriate integration of the use of 2D and 3D media has resulted in some success in the consolidation stage. Unfortunately, this integration has historically been difficult to achieve.

Acquisition Stage

A wide variety of two-dimensional media have been used effectively in the acquisition stage. These media include various print materials, e.g., textbooks, programmed texts, and workbooks; photographic materials, e.g., photographs, slides, movies, and video; art work; and audio materials. Perhaps the most powerful 2D medium in existence at present is the relatively new technology which combines the use of interactive videodisc and computer graphics in a single device.

Evaluation Stage

Historically, the preferred 3D medium for the evaluation stage has been actual equipment trainers (AETs). Limitations inherent in using AETs have resulted in the growing use of simulators. These simulators have included various levels of physical and functional fidelity, ranging from low fidelity flat panel simulators to high fidelity 3D replications of actual equipment. The degree of fidelity required is a function of the tasks to be evaluated.

Consolidation Stage

The consolidation stage requires use of both 2D and 3D media. Any of the media identified above can be used effectively in this stage. But, it is apparent from the requirements for this stage, as discussed above, that all of the media used in this stage must work together as a unified whole. This requires the use of some intelligent controller to coordinate the student's interaction with all of the media employed. The use of an instructor as controller is inefficient in terms of both time and money. When administrative factors dictate a high student to instructor ratio, the training can be ineffective as well.

Recent advances in technology allow extensive use of computers in the consolidation phase. Computers are used to control 3D simulators, to control videodisc players, and to control other peripheral equipment. This allows the use of the computer as the intelligent controller in the consolidation phase. This mix of 2D, 3D, and computer as controller is likely to be the most effective means of providing training in this consolidation stage.

INTEGRATED SYSTEM CONCEPT

The above discussion indicates the need for a system which integrates the use of both 2D and 3D media. Such a system could be effectively used in all three learning stages. The 2D portion used alone could be used for acquisition applications, while the use of the 3D by itself would suffice for evaluation. In addition, the integration of the use of the two in various proportions would make it a potent, cost- and training-effective instrument in the crucial consolidation stage.

Until recently, technology has not been available which would allow the integration of 2D and 3D media into a unified system. Recent breakthroughs have allowed the Grumman Aerospace Corporation to design and construct two such systems, and they are currently under operational evaluation.

AMTESS

The Army Maintenance Training and Evaluation Simulation System (AMTESS) is a generic maintenance training system developed for the U.S. Army, Project Manager for Training Devices. The version of AMTESS developed by Grumman [1 3] consists of two modules: a student station and a 3D simulator (See Figure 1). These two modules can be used as independent elements, or they can work together as an integrated system.

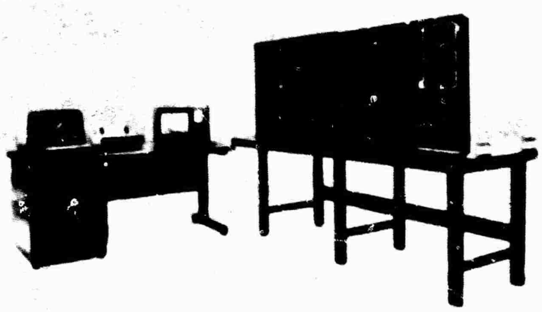

Figure 1 Integrated AMTESS Modules

3D Module. 3D simulator modules can be either system or training program specific. Math models cause each module to react as the real equipment it simulates would under both normal and degraded conditions. These models make no judgment as to the correctness of student actions. The 3D simulator provides the technician with the opportunity to manipulate controls, observe indicators, and troubleshoot malfunctions on equipment that is physically and functionally representative of the actual equipment. Computer control of the 3D via a microprocessor provides all of the normal and abnormal indications of all components, controls, and indicators.

Two different prototype 3D modules have been delivered and currently are under evaluation. An automotive module designed to train generating and starting system troubleshooting on the M110A2 self-propelled howitzer is at Aberdeen Proving Ground, Maryland (See Figure 2), and a missile module designed to train troubleshooting on the transmitter of the High Power Illuminator Radar of the HAWK Missile System is at Fort Bliss, Texas. (See Figure 3).

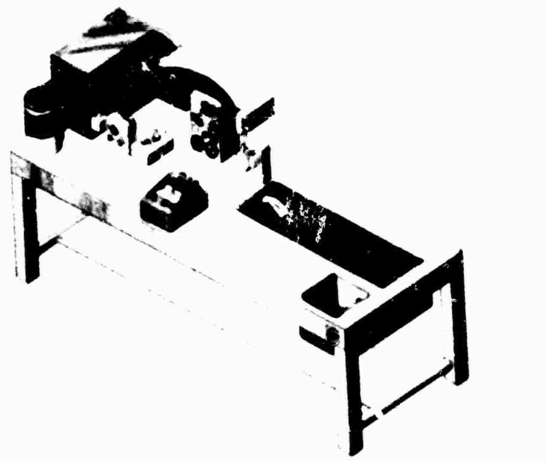

Figure 2 AMTESS Automotive 3D

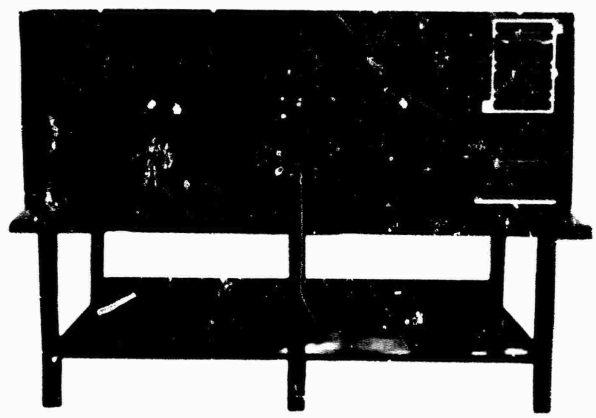

Figure 3 AMTESS Missile 3D

2D Module. The 2D module can be used in a stand-alone mode, or it can be connected to any 3D module for tandem operation (See Figure 4). Two-way communication between the student and the 2D is accomplished using a color television monitor, which can display videodisc and/or computer generated images. Student 2D responses are registered through a touch bezel attached to the TV monitor. The videodisc player, TV monitor, and touch bezel are all under the control of a single microprocessor with dual drive floppy disk. When operating in tandem, the 2D processor also controls the 3D simulator.

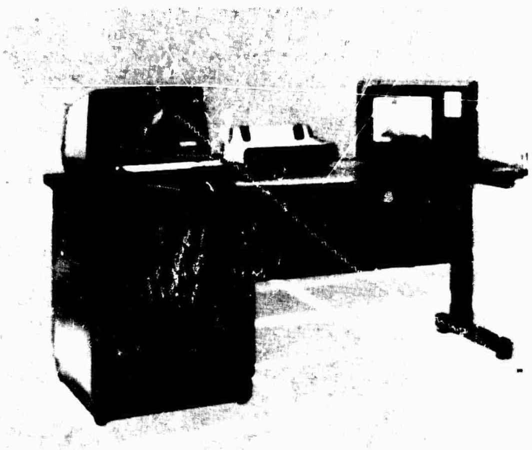

Figure 4 AMTESS Student Station

The 2D can be used for various types of instructional activities, e.g., presentations, tutorials, or drill and practice. Various instructional techniques can be used to facilitate student learning. For example, modeling of expert behavior on the 2D can be followed by immediate student immitation of the modeled behavior on the 3D. The 2D can monitor student actions on a continuous basis. It can branch to provide specific guidance, remediation, and/or feedback as appropriate.

TJS

The Tactical Jamming Sustem (TJS) trainer for the U.S. Navy's EA-6B aircraft was developed for the Naval Air Systems Command, and has been delivered to the U.S. Naval Air Station, Whidbey Island.[4] While configured somewhat differently than AMTESS, the TJS contains the same elements, i.e., videodisc, computer generated graphics, student response touch bezel, computer control, and 3D simulation. (See Figure 5). The TJS trainer is weapon system specific, and although it could be modified for other applications, e.g., the training of operator procedures, it was developed to address TJS maintenance training requirements.

SYSTEM TRAINING CAPABILITIES

Integrated System Trainers (ISTs) are an answer to the requirement for concurrent use of 2D and 3D media in the consolidation stage. Having both 2D and 3D capabilities, they also have full capability for use in the acquisition and evaluation stages. The ability to deliver that training using a variety of methods and

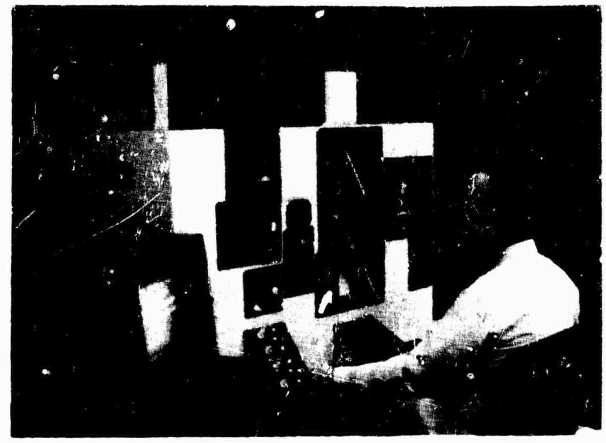

Figure 5 TJS Maintenance Trainer

techniques has been demonstrated in the lessons developed for the AMTESS and TJS systems. The following paragraphs describe the ways in which various features of the ISTs have been used.

The heart of an IST is the computer in the 2D, which controls the student's interaction with all elements of both the 2D and 3D modules. It monitors his progress and provides cues, prompts, instruction, knowledge of results, and help to the student in accordance to developed lesson materials. The student interacts with the 2D using the touch bezel attached to the video screen, and his manipulations of the various components on the module are reported to the 2D computer using the communication lines between the modules.

On the 2D module, videodisc images have been used to store instructional materials in the form of textual, graphic, pictorial, and auditory information. The random access capability of the player allows the computer to call up either single frame or motion sequences in an order that is appropriate for instructional requirements. The motion capability can be used to present audio, visual, or audiovisual sequences. Two audio channels on the disc permit additional flexibility of use.

Computer generated graphics extend the capability of the videodisc, and provide a quick and easy way to update lessons. The generation of these computer presentations is under 2D computer control, so the messages can be tailored to individual circumstances. Communication between the 2D and 3D computers allows the system to call up video and computer graphic images in response to student actions.

Use of the 2D computer as the executive permits the two parts of the system to be used in any desired proportion. This flexibility allows lesson materials to be tailored to the specific requirements of each learning stage.

This not only increases instructor reliability, and consistency of training, it permits the instructor to use time more efficiently. This allows the instructor to become more of a resource manager, using all of his available tools, and additionally frees the instructor to spend time with those students who would best benefit from that direct interface.

During the acquisition stage, videodisc images and computer graphics have been used extensively to provide cues, prompts, and remediation, and for student requested help sequences. Various levels of help have been made available, with alternate paths based on student performance. Relatively speaking, very little use of the 3D module has been made during this stage.

During the consolidation phase, the student is weaned from dependence on the 2D. Fairly heavy use is made of the student station early in this stage, as it guides his interactions with the 3D. By the end of this stage, however, the student interacts almost exclusively with the 3D and interacts with the 2D only when he specifically asks for help.

In the evaluation stage, the 2D continues to monitor individual actions to maintain records of student performance. The interaction monitored will be almost entirely with the 3D, and virtually no video or computer generated messages will be used.

THE FUTURE OF SKILLS TRAINING

ISTs are currently being evaluated for training effectiveness and transfer of learning. Their potential for providing effective training in all three learning stages will be realized as lessons are developed which use the diversity of methods and techniques available, and are applied across a wide range of training programs.

New applications are in progress. Technology for training devices is constantly improving. Microprocessor technology continues to grow. The new generation of videodisc development will likely include single frame audio and programmable videodiscs. Integrated Systems Trainers are the future of skills training.

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A COMPUTER-BASED JOB-AID FOR MAINTAINING COMPLEX MILITARY HARDWARE

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ABSTRACT

The task of maintaining complex military hardware in the field has become a major problem facing all the military services. Contributing to this problem are the mass of highly technical and instructionally inadequate manuals and the low reading ability and inexperience of many military technicians. Solutions have been attempted in several areas, mostly at high cost and with little success. One promising solution appears to be the use of computer-based job-aids for the technician in the field. One such system is NOMAD (Navy On-board Maintenance Aiding Device), a prototype computer-based job-aid developed by Hazeltine Corporation's TICCIT division and U.S. Navy personnel for ship-board maintenance of the Navy's MK-86 fire-control system. NOMAD has proved very successful in its initial tryout.

THE PROBLEM

One of the most important tasks facing all the military services today is that of maintaining complex systems used in the field. The volume of printed documentation that has accompanied the introduction of such systems has grown so large that much of it cannot be accessed quickly enough to make it useful for field level maintenance. In addition, such information is difficult to store, difficult to update, and often written and illustrated at too high a level to be intelligible to military technicians. The problem is further aggravated by the low reading ability of many of today's military personnel.

The magnitude of the military maintenance problem has been thoroughly documented.[1,2,3] The crux of the problem has been identified as the inability of technicians to troubleshoot and repair complex systems rapidly and accurately. This problem is manifested by a high percentage of errors in troubleshooting and extended and eventually unacceptable time to repair the equipment.

ATTEMPTED SOLUTIONS

Approaches in the following areas have been taken to attempt to overcome the military maintenance problem:

1. Formal and on-the-job training
2. Modularization of weapons systems
3. Development of Built-in Test Equipment (BITE)
4. Development of Automatic Test Equipment (ATE)
5. Development of high quality technical manuals
6. Research on the fundamentals of the man-machine interface

Let us now consider each of these approaches in detail.

1. Formal and on-the-job training. Despite increased expenditures on training in the military community, this approach has had limited success for the following reasons:

a. Long-term delays between training and on-the-job applications. A particular fault may occur so infrequently as to make it impossible for the technician to be practiced at locating and correcting it. Such a fault may occur years after the pertinent training.

b. Sophistication of equipment. The task of the technician becomes more sophisticated when modularization is introduced because he or she must deal with complex inter-relationships among whole subsystems, rather than individual faulty parts.

c. Out-dated training techniques. With only a few exceptions (such as the use of modern computer-based training systems) many military maintenance training techniques are twenty to thirty years behind accepted learning theories and practices.

d. Loss of skills. Usually, formalized military training programs for technicians do not allow for refresher and updated training while on the job. Necessary detailed knowledge and skills are, therefore, lost.

2. Modularization of weapons systems. While modularization was intended to simplify the technician's task by having him or her remove the faulty module and replace it, the success of this approach depended on the diagnostic ability of the technician, the ability of the technician to replace the module without damaging the system, and the availability of replacement modules. The first two of these factors are dependent on the quality of the personnel entering the training system and the ability of armed forces to retain expert technicians. Both of these areas have been problems in recent years.

3. Development of Built-In Test Equipment (BITE). BITE is designed into the system to be tested at the time of its construction and therefore must be designed at the same time as the system itself. Unfortunately, it is usually not possible to forecast accurately all possible types of faults at the time of system design. In addition, BITE has proven unsatisfactory because:

a. Deficiencies in BITE are extremely difficult to correct, since BITE is initially designed into the system.

b. If it is to identify more than 60% of the faults in a complex system, BITE must be so complex itself that it becomes hard to troubleshoot and maintain.

c. BITE does not provide aids for performing replace and repair functions.

4. Development of Automatic Test Equipment (ATE). ATE consists of very large, complex, and expensive devices designed to be connected to the system to be tested. ATE is commonly used for troubleshooting and maintenance of military aircraft such as the F-16. ATE is impractical in many maintenance and troubleshooting situations because of its expense and size. This approach is only feasible for depot level maintenance.

5. Development of high quality technical manuals. Such an approach has not proved effective because:

a. Paper manuals are bulky and hard to handle.

b. Paper manuals are difficult to update.

c. Access time is excessive when large numbers of manuals are needed to explain a single system.

d. Information in this form is usually hard to understand and is usually not designed to meet the needs of different levels of users from novices to experts.

6. Research on the fundamentals of the man-machine interface. All the approaches described above have proved deficient. Therefore, further research into the man-machine interface appeared to be necessary. Several directions for research have been followed:

a. One proposed research solution to the problem has been to study the manner in which expert technicians troubleshoot and maintain complex systems. It was hoped that an increased understanding of expert knowledge would lead to improvements in training techniques for novice technicians. Although much interesting work has been done in this area, no major improvements have yet taken place in the training of technicians, and as a result no major improvements in weapons system availability have resulted from this research.

b. A second potential solution is to model complex systems, such as steam plants, in computers. It is thought that an improved understanding of how such systems function and how people operate, troubleshoot, and maintain such systems will result in improved approaches to troubleshooting and maintenance. Such simulations are based on mathematical models of complex systems. The meters, dials, and other indicators of system functioning are represented as graphics on computer displays. While this approach may have value in the distant future, it seems clear that no major improvements in training or maintenance and troubleshooting may be expected to develop in the near future. These complex simulations are based on mathematical models that are extremely expensive to develop, and as yet they have had little impact on weapons system availability.

c. A third approach is to employ computer-based job-aids designed to deliver troubleshooting and maintenance information in the field. In this approach a computer terminal with access to an interactive data base is made available to the technician at the job site. An example of this is the U.S. Navy sponsored effort to develop a prototype of one such system for ship-board use. This device, called NOMAD (Navy On-board Maintenance Aiding Device), provides a structured, automated diagnostic strategy that prompts and logically leads technicians through appropriate procedures and actions in troubleshooting the Navy's MK-86 fire-control system. The MK-86 fire-control system is an extremely complex gunfire control system designed to protect Spruance class destroyers from hostile aircraft and missiles. Although the MK-86 system is effective when operating properly, it has been prone to failure due to a shortage of the experienced technicians required to troubleshoot and maintain it. The remainder of this paper describes the application of NOMAD to this problem.

NOMAD: A PROTOTYPE SOLUTION

NOMAD is currently aboard the U.S.S. Kinkaid, a Spruance class destroyer in the Pacific, where it is undergoing test and evaluation. NOMAD is being used on the Kinkaid for MK-86 system familiarization (for junior technicians), troubleshooting and diagnostic procedure prompting, fault isolation prompting, MK-86 checkout and grooming, and presentation of videotape maintenance procedure sequences. (NOMAD is capable of both videotape and videodisc presentations integrated into computer-generated text and graphics, under computer control.)

The scope of the troubleshooting and maintenance material currently available on NOMAD is limited to those areas of the MK-86 system most prone to failure. This subset of material was determined by the Navy to be adequate for purposes of this evaluation.

Physically the NOMAD system is composed of a minicomputer and peripheral hardware located onboard in the ship's data processing center. Two interactive color terminals with keyboards and light pens are strategically placed within the ship to allow ready access to the MK-86 hardware. One terminal is located in Radar Room Number 1 and the other in the Combat Information Center. The current two terminal system is expandable to 32 terminals should the need arise. The repair technician communicates through the NOMAD terminal with the troubleshooting database and algorithm stored in the computer.

PROGRAM DESIGN CONSIDERATIONS

Key aspects of the NOMAD program include the use of (a) commercially available, off-the-shelf hardware and software, only slightly modified for a shipboard environment (NOMAD is a compact version of the TICCIT* computer-assisted instruction system manufactured by Hazeltine Corporation), (b) U.S. Navy enlisted personnel (one Senior Chief and two sailors) to provide the subject matter expertise, create the troubleshooting and maintenance material, and put it on the computer, and (c) rapid implementation of the concept (seven months from concept to functioning hardware and software aboard the Kinkaid.

The significance of NOMAD as a prototype device lies not in its hardware but rather in the toubleshooting algorithm, database, and presentation mode employed in the system.

The troubleshooting strategy implemented in NOMAD adapts to the level of expertise of the user, leads him or her to the fault in the system, and prescribes the required corrective action. Where possible, the system references the appropriate technical documentation rather than duplicating it. NOMAD also keeps detailed records of each technician's use of the system during troubleshooting. The major goal in implementing such a system is to deliver the expert's knowledge to the technician. This must be accomplished by first transferring that knowledge to the computer. Ideally this transfer should be made rapidly and inexpensively, which requires an easy-to-use software system on which the subject matter expert (SME) may work directly to impart his or her knowledge and with which the end user can interface easily and effectively.

These considerations indicate a need to focus on the man-computer interface rather than the computer hardware package. There is a great temptation for those working in this area to attempt a hardware solution to this problem--that is, to decide in advance that a computer-based job-aid should be of a certain weight, of a certain size, have a display area of certain parameters, etc. Rather than take this approach, Hazeltine Corporation staff are systematically focusing on what we consider to be the crucial concerns here, all of which are aspects of the man-computer interface. Specifically, a computer-based job-aid should:

1. Make the knowledge of the SME available to the novice in a form that makes it easy to understand and effective in helping him or her solve maintenance and troubleshooting problems. The NOMAD program is based on the idea that it is not necessary to provide a deep structure representation of the SME's knowledge in the computer-based job-aid. All that is required is that the expert make explicit his or her troubleshooting and maintenance approach and then represent that approach in the computer's programming. Neither is it necessary to attempt to arrive at some objective specification of expertise. Instead, a single, effective approach is made available to the inexperienced but school-trained technician. Experts differ in their conceptualizations of complex systems and in their strategies in troubleshooting such systems. All that is really needed, however, is one approach that works.

2. Utilize a user-friendly software system to create the troubleshooting logic and maintenance procedures. NOMAD utilizes an existing commercial user-friendly language, called TAL (TICCIT Authoring Language), which was designed for the authoring of flexible instructional presentations and simulations. It has also proven effective and easy to use in the present application. Although most of the authoring was performed at a land-based facility before installation of the on-board system, the system allows for on-site authoring as necessary.

3. Utilize a user-friendly graphics system to create graphics of wave forms, instrument panels, etc. A commercially available document camera, part of the TICCIT system, was used for putting NOMAD graphics on line. This camera and its associated software package allow graphics drawn by illustrators or found in Navy technical manuals to be scanned into the computer system in minutes. These graphics are then edited using an on-line graphics software package. Graphics are colored, rotated, expanded, and reduced as required. The graphics editor can also be used to create unique symbols or characters, which can be assigned to keys on the keyboard and stored for subsequent use. The ease with which one can construct graphics makes it possible to staff an effort like the NOMAD program with inexperienced personnel, such as entry-level enlisted people. The document camera is not part of the ship-board hardware package, so graphics were digitized at the land-based facility. However, the graphics software package is available shipboard to make any necessary modifications identified on site.

NOMAD graphics are displayed instantaneously as one image rather than being drawn slowly as the technician watches. In situations that require the use of complex graphics, this high-speed display capability is critical to clarifying complex technical text.

4. Utilize state-of-the-art instructional design techniques such as hypertext to ensure that the performance of technicians is as efficient as possible. Data are presented at various levels from direct access for the experienced technician to a guided step-by-step approach for the novice, with a wide variety of possibilities between. The major interface between the technician and the computer is through a light pen for pointing to locations on the terminal screen rather than by typing inputs on the terminal keyboard. This speeds up the troubleshooting process and avoids the problem of poor spelling and/or typing skills on the technician's part.

PRELIMINARY RESULTS

At the present time, very little quantitative data on the preliminary try-out has been made available. However, the existing results indicate that this approach is very successful in increasing weapons system availability. We expect to receive enough additional data about NOMAD's performance to draw meaningful conclusions about the following topics:

1. Reliability of the ruggedized commercial hardware in the shipboard environment.

2. Attitudes of U.S. Navy technicians toward using an interactive computer-based information system.

3. An assessment of the potential of the system to significantly improve MK-86 operational readiness and system availability indices, given an expanded data base to cover all suitable MK-86 subsystems. (Only a subset of such systems are now included in the NOMAD programming.)

Tentative results in these areas are summarized here:

1. Reliability. The prototype NOMAD system is not a ruggedized system except for six shock mounts attached to the equipment rack. Nevertheless, the off-the-shelf system hardware has survived at sea since January, 1982, and has continuously functioned well with only short, minor interruptions such as were expected in this first test of the system at sea. After an initial break-in period, the Navy technicians have been successful in operating NOMAD at sea with little or no help from contractor representatives, despite having received only cursory hardware training. Successful operation has been performed during the firing of the ship's 5-inch guns and at times of heavy seas.

We can only assume that a fully ruggedized production version of the system would perform as well as or better than the present system.

2. Technicians' attitudes toward such a system. Technicians' attitudes have been very positive toward the system. In fact, they would like to see additional programming to cover other sections of the MK-86. Technicians were also impressed with the ability of the system to present videotapes of maintenance procedures. Favorable reactions have been expressed by crew members of other ships who have seen the system demonstrated, as well as by various visiting dignitaries. Attitudes towards the NOMAD system were so positive that the Captain of the Kinkaid requested that the system be retained on the ship rather than be removed at the end of six months as had been originally planned.[4] This requst was granted.[5]

3. System potential. The following data on sample fault isolation times with and without NOMAD have been provided by Naval Ship Weapon Systems Engineering Station (NSWSES), Port Hueneme, California, for the photo tube assembly (10A5A5) and power supply (19PS5).[6] Data without NOMAD come from other ships as well as the Kinkaid. Individual times presented represent separate events.

	Troubleshooting Time (hours)	
MK-86 Subsystem	with NOMAD	without NOMAD
Photo Tube Assembly	.50	1.60
	.17	3.20
		1.40
		.20
Average	.34	1.60
Power Supply	.33	.21
		.50
		.50
		.90
Average		.53

It has been recommended that "NOMAD should be expanded to encompass the entire MK-86 system to truly prove its value as [a] troubleshooting and maintenance aid device."[7]

Ideally, there would have been a formal effort to collect quantitative data for the above categories of information and compare them to baseline data. This was not possible, so instead a general assessment is being collected for each category based on at-sea experience as reflected in appropriate system logs. Additional data will come from narrative reports from chiefs and officers in the weapons department.

The reports prepared on NOMAD include:

1. A biweekly Situation Report from the USS Kinkaid, which includes comments on the usefulness of NOMAD as a maintenance tool and as a tutorial aid.

2. A monthly report from NSWSES containing an analysis of all data collected in the month reported.

3. A preliminary report from NSWSES, scheduled for published in October, 1982, after completion of the trial period, addressing the analysis results for Naval Sea Systems Command.

4. A final report from NSWSES, scheduled for publication in November, 1982, for Naval Sea Systems Command approval and distribution.

THE FUTURE

It should be noted that in addition to its MK-86 related functions, current additional uses for NOMAD aboard the Kinkaid include shipboard indoctrination, EPICS (Enlisted Personnel Individualized Career System) training support, and recreational applications. NOMAD could also deliver the same instructional materials available on any of the TICCIT systems currently in use for Navy and Marine Corps training.

The success of NOMAD has cleared the way for future, enlarged versions of this prototype system. An RFP has been received by Hazeltine concerning a second system for use on an Atlantic-based ship. Development of a more compact version of NOMAD hardware, based on a microcomputer, is now under way.

Much of what has been learned about how to design job-aiding material during the NOMAD program is applicable to other military hardware systems. The potential for this solution to providing help to technicians in the field seem unlimited.

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LESSONS LEARNED IN THE APPLICATION OF SIMULATION TO JET ENGINE MAINTENANCE TRAINING

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ABSTRACT

Technical training and the isolation and diagnosis of jet engine malfunctions has traditionally been accomplished using operational engine hardware, which has limited malfunction training. Simulated aircraft maintenance training (SAMT) devices are being increasingly employed by the military to achieve more efficient and controlled instruction in maintenance procedures. The F-16 engine diagnostic SAMT is comprised of simulated aircraft cockpit and test equipment control panels, an instructor station, and a computer simulation of the Pratt & Whitney F-100 engine. The math model, which consists of a data base of engine variables, with transients provided by simple algorithms, was found to provide completely realistic engine performance for maintenance training. Through the model, students can practice trimming procedures, and diagnosis of a variety of engine component failures. Valuable lessons were learned in regards to sources of data for data base and algorithm development, data base fidelity, and approaches to malfunction model development.

BACKGROUND

Technical training in jet aircraft engine trimming procedures and in the isolation and diagnosis of jet engine malfunctions has traditionally been accomplished by using operational engine hardware; either a complete aircraft or the engine assembly.

The use of "Hot Mockups" for teaching engine trimming has the drawbacks of (1) a noisy teaching environment, (2) exposing the student to hazards which are not a vital part of learning how to trim an engine, (3) the always-present competition with other groups for aircraft hardware; historically, training usually has a lower priority than operations and maintenance, and (4) trimming an engine burns a substantial amount of fuel and results in significant wear on the engine. Data from recent USAF engine trim courses indicate that it requires 30,000-40,000 lbs of fuel and approximately 8 hours of engine time to train each student.

For these reasons, simulated aircraft maintenance training devices are being increasingly employed by the military to reduce costs and achieve more efficient and controlled instruction in maintenance procedures.

THE F-16 ENGINE DIAGNOSTICS SAMT

An example of this new approach to maintenance training is the F-16 Engine Diagnostic Simulated Aircraft Maintenance Trainer (SAMT), comprised of two 3' x 8' panels, an instructor station and a computer simulation of the Pratt and Whitney F-100 engine. The two panels contain aircraft cockpit instruments, engine drawings and blowups of selected components as well as relevant test equipment control panels. They also contain a set of 130 action switches, which allow the student to simulate the taking of various actions; for example. an action switch is used for applying ground power. A set of 70 element switches are distributed within the panels which allow the student to designate particular components; for example, an element switch is used to designate the engine alternator as a defective component.

The instructor's station is comprised of a CRT display and keyboard which allows the instructor to choose one of a set of engine malfunctions for the current lesson and to record student information relevant to the training. An instructional feature of the software prompts the student with caution and hazard messages, and records student performance as the lesson progresses.

SAMT training has been well accepted, saving 30,000-40,000 lbs of fuel per student and 50% of student training time over flight line training; also, to show the current emphasis on malfunction training, the students in the six day USAF F-100 Engine trim course spend four days on the SAMT diagnosing malfunctions.

THE MATH MODEL

The key to successful simulation of the jet engine, cockpit instruments and engine test sets is the math model which underlies the computer-driven display panels. Through the model, students can practice time consuming, tedious and expensive trimming procedures at substantially reduced cost. Selectable malfunctions allow for diagnosis and isolation of a variety of engine component failures.

The engine model and test set models interact to form a totally free-play environment. The student is free to make mistakes on both engine operation and test set operation, and the system is designed to give the appropriate response. A simple real time monitor is included in the simulation to detect and flag student operational and procedural errors.

Traditional approaches to jet engine modeling have involved mathematical description of complex mechanical and thermodynamic processes. This approach when applied to maintenance trainers is both costly and unnecessary.

THE ENGINE MODEL

A new approach was chosen for the math model of the engine which is driven by a data base of engine variables that describe the steady-state behavior of the engine. The transient responses are provided by simple algorithms. This approach was found to provide completely realistic engine performance for maintenance training.

The engine data base consists of 22 tables which describe the engine variables in normal and diagnostic modes. The normal engine parameters data consist of tabulated values for nine observable parameters; fuel flow, nozzle position, variable vane position, compressor and turbine RPM, two temperatures, and two pressures. In addition to the normal engine tables, data is tabulated for the engine operatinng without the engine electronic controller (EEC) and with the back-up controller (BUC). Seven different engine trim tables and 12 malfunction tables complete the set.

Each of the tables (Refer to Table 1) is composed of three sub-tables; one for each of three values of outside air temperature. For a given outside air temperature, the steady-state value of each of the nine parameters is tabulated for incremental values of throttle setting. The tabulated values were obtained using the manufacturer's comprehensive non-real-time engine simulation program.

Refinements to the tabulated values are then made to the nine parameters to simulate the function of six trim screws, engine electronic controller, back-up controller, ambient air temperature, air source selector, anti-ice switch, starting fuel switch (lean/rich), false parameters introduced by various engine test sets, and parameter perturbations due to simulated malfunctions. (Refer to Figures 1 & 2.)

The model includes 32 classifications of malfunctions which fault isolate to 75 unique problems. The malfunction models are either table-driven, algorithm-driven or are a combination of the two. Referring to Figure 1, the malfunction symptoms are either inserted during throttle movement, incorporated into the engine controller algorithms (BUC or EEC), absorbed in the steady-state tables or added at the time of engine transient response. Figure 2 is included to show what is involed in calculating a typical parameter in real time.

Engine transients involve the time behavior of parameters toward the steady-state values corresponding to throttle position. A satisfactory and simple method which we use to model these transients proved to be an exponential response for each engine parameter of the form. (Refer to Figure 3.)

$$X(T) = Ae^{-\frac{T}{TC}} + B(1 - e^{-\frac{T}{TC}}) \qquad (1)$$

Where

A = Steady-state value of the parameter at initial throttle setting A.

B = Steady-state value of the parameter at final throttle setting B.

X(T) = Value of the parameter at time T.

TC = Time constant

Note that the classical form of the response in eq (1) is computationally difficult and involves the evaluation of exponentials. A more efficient form is found by developing a recursion relationship:

From (1) letting $t = N\Delta T$

TABLE 1

TYPICAL DATA BASE TABLE

Parameter	Throttle (Degree)	Ambient Temperature 0 deg	45 deg	100 deg
RPM	20	-	-	-
	23	-	-	-
	26	-	-	-
	35	-	-	-
	44	-	-	-
	50	-	-	-
	68	-	-	-
	80	-	-	-
	83	-	-	-
NOZZLE	20	-	-	-
	23	-	-	-
	38	-	-	-
	50	-	-	-
	53	-	-	-
	65	-	-	-
	80	-	-	-
	91	-	-	-
	109	-	-	-
	115	-	-	-
	127	-	-	-
	130	-	-	-
TEMPERATURE	20	-	-	-
	23	-	-	-
	26	-	-	-
	32	-	-	-
	35	-	-	-
	42	-	-	-
	45	-	-	-
	51	-	-	-
	59	-	-	-
	68	-	-	-
	79	-	-	-
	83	-	-	-

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(etc for all 10 Parameters)

FIGURE 1. ENGINE DIAGNOSTICS SIMPLIFIED FUNCTIONAL DIAGRAM

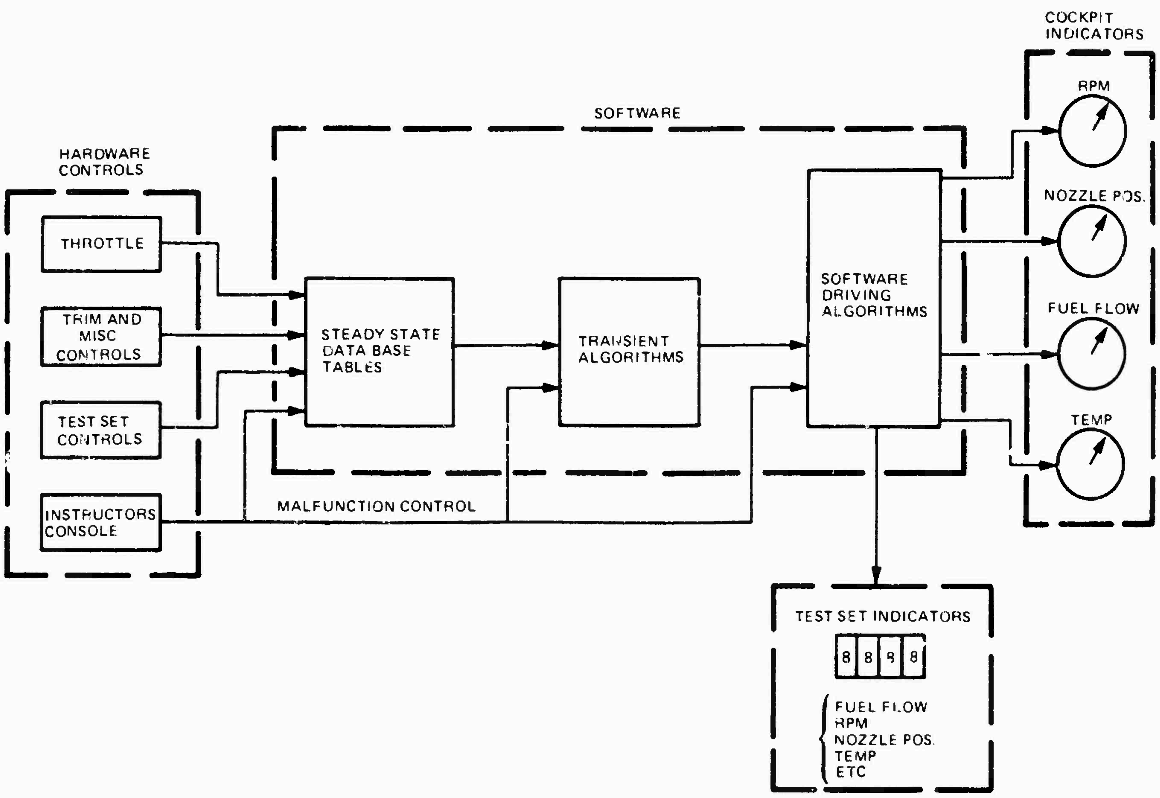


FIGURE 2 ENGINE DIAGNOSTICS SIMULATION
(CALCULATION OF A TYPICAL PARAMETER)

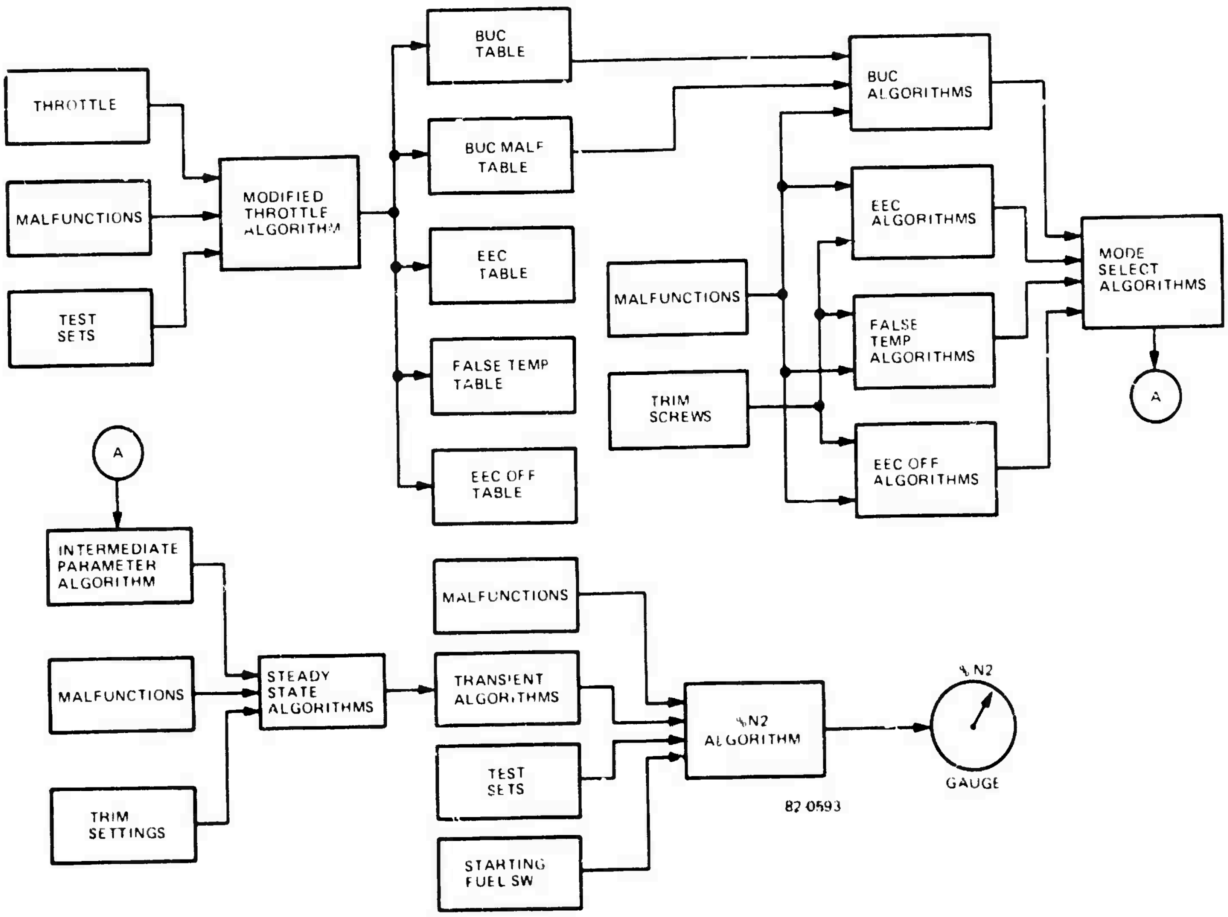
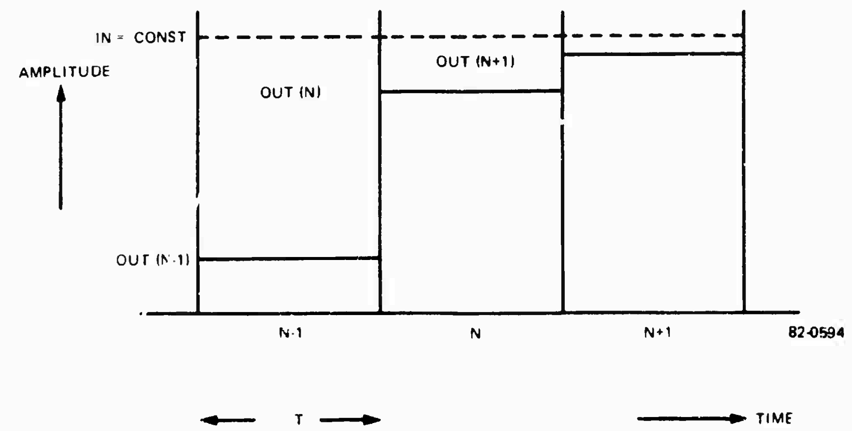


FIGURE 3. EXAMPLE OF EXPONENTIAL RESPONSE



1. A constant input, IN(N-1), is applied at time step N-1.

2. The output at the Nth time step, OUT(N), is 100K% of the interval IN(N-1) - OUT(N-1).

3. The output at the N+1st time step, OUT(N+1), is 100K% of the interval IN(N+1) - OUT(N).

4. The process repeats for subsequent time steps, thus generating an exponential rise from OUT(N-1) to IN(N-1).

$$X(N) = Ae^{-\frac{N\Delta T}{TC}} + B\,[1 - e^{-\frac{N\Delta T}{TC}}]$$

by substitution from (1) and collecting terms

$$X(N+1) = e^{-\frac{\Delta T}{TC}}\, X(N) + B(1 - e^{-\frac{\Delta T}{TC}}) \quad (2)$$

Equation (2) can be written in a more computationally efficient form:

$$OUT(N+1) = OUT(N) + [IN(N+1) - OUT(N)]*K$$

Where

OUT(N+1) = Current value of the parameter

OUT(N) = Value of the parameter computed at the last ΔT time step

IN(N+1) = Current steady state value parameter (a function of throttle setting)

K = K(ΔT,TC)

TC = Time constant

ΔT = Calculating increment (0.1 second in our case)

This form is arrived at by using the Laplace transform of the exponential.

$$\frac{1}{TC*S+1}$$

and Euler's numerical integration formula

$$X(N+1) = X(N) + \dot{X}\Delta T$$

to obtain,

$$IN = TC*\frac{d(OUT)}{dT} + OUT$$

Which leads to

$$OUT(N+1) = OUT(N) - [IN(N+1) - OUT(N)]\,\frac{\Delta T}{TC}$$

In other words, for each time step, the current value is determined by adding K times the difference between the forcing function, IN(N+1), and the last parameter value, OUT(N), to the last parameter value (Refer to Figure 3). If the forcing function (throttle position) remains constant, this is a classical exponential response to a stimulus.

LESSONS LEARNED

Things We Did Wrong

Improved Malfunction Definition. In the early stages of trainer development, not enough attention was paid to malfunction definition. Since our model does not directly employ the basic physical principles of the engine, but rather relies on a data base for symptomatic description, the secondary malfunction responses are not inherent in the model. (An example of a primary response is an oscillating exhaust nozzle, whereas the secondary responses are the changes to the other engine parameters which occur as a consequence of the fluctuating nozzle.) The modeling of these minor (but important to diagnostic training) responses must be carefully specified. However, because of their secondary nature, it is difficult to obtain general agreement on what these responses should be. The manufacturer's data was generally accepted as the most reliable and tended to resolve the differences. In retrospect, the manufacturer should have been consulted in more detail. We also we should have relied more heavily on F-15 engine data, since the two aircraft have the same engine and F-15 had been operational for some time.

Added Audio and Visual Cues? No provisions were made for special diagnostic audio responses and we discovered at a rather late date that the engine Job Guides require the maintenance man to listen for igniter plug noises. He is also required to look for fire coming from the tips of the igniter plugs, and visual indications of igniter firing were not provided for. Adding these special audio and visual effects might be desirable.

Things We Did Right

Exponential response proved to be Simple and Effective. The selection of this type of response to describe engine transient phenomena proved to be a wise choice. We employed more complicated approaches (notably series and parallel networks of exponential responses) in other trainers. Where these approaches were tried on the Engine Diagnostics SAMT the improvements were negligible even when instrumentation was employed.

Improved Method of Tracking Equipment Changes. As the engine and test sets evolve and new operational hardware appears, the problem is ever-present on how often to retrofit the trainers and what to do to accommodate the missing hardware in the meantime. A very workable and inexpensive method was devised consisting of software "bridges", which are a CRT message to the student to describe equipment responses. For example, if a voltage is to be measured and a voltmeter is not included on the trainer, the message "Voltmeter reads 22 Volts" appears at the proper time in the lesson.

Model Accommodates Other Jet Engines. Since transient responses are not of primary importance in the teaching of engine diagnosis, (readings are always taken after the engine stabilizes) the use of the exponential response is probably adequate for any jet engine. It is therefore likely that the model can accommodate most any jet engine by changing the data base (and using appropriate engine parameters) and some time constants.

Things We Should Have Done Better

Reduced Computation Time. Since the engine model as well as the test set models are table-driven, the basic trade-off's in table structure are:

(1) Polynomial fits to the data with no breakpoints - the table consists of coefficients of the polynomials.

(2) Breakpoint logic - only the vertices are retained and the parameters are computed by linear interpolation. (Refer to Table 1)

(3) Slope/Intercept form - the vertices are retained as in breakpoint logic but the slope and intercept are pre-computed and stored as table entries.

Method (1) was ruled out because we were unsure of the fidelity necessary for training and high fidelity requires a very high degree of polynomial to adequately describe the data. Since a polynomial of degree N requires N multiplications and N additions for each evaluation, high degree polynomials are precluded because of real time constraints.

Method (2) requires about three times the computational time of that of method (3) in order to compute a parameter value but requires only half the table size, however, Method (2) was chosen because at the time of model design (1978 time frame) computer memory was considerably more expensive than it is today.

As it turned out, some of the actual data differed significantly from the breakpoint data employed and proved to be entirely satisfactory. Since the actual breakpoint data provided realistic performance, we now think that we could achieve a significant improvement by employing various data compression methods and still not degrade training effectiveness.

Reduced Memory Requirements. A similar trade-off exists in the data base structure. The current method of employing different engine parameter tables for various cockpit switch combinations and malfunctions, leads to large memory requirements, which could be sharply reduced by restructuring the data base to include one primary table of engine parameters and judiciously adding switch-dependent polynomial fits of deltas to these basic parameters. In fact, we suspect that the one remaining table could be significantly reduced by opting for a coarser data structure as noted above.

Missing Cockpit?. All engine maintenance procedures are a two man operation: One man is in the cockpit and the other is operating the test equipment. One of the difficulties facing recent engine training class graduates is how to locate the many cockpit switches that must be placed in the OFF or SAFE position in order to make the aircraft safe for maintenance. (This procedure must preceed any maintenance action.) It may be advantageous to include a simulated cockpit with many of the switches dead-ended but moveable. All engine related switches would be operational.

SUMMARY

The simple model consisting of a data base of steady-state engine parameters, coupled with an exponential response for engine transients proved to be a very effective approach.

We feel now that we could go back and make substantial improvements in table structure (data resolution and data base compression) and computation time.

The manufacturer should be consulted more at the start of the program, particularly in the area of malfunction definition. In doing so we could have avoided the problems of partially- defined and ill-defined malfunctions.

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THE FEASIBILITY OF EMPLOYING AN IN-COCKPIT DEVICE TO PROVIDE MOTION CUES TO THE PILOT OF A FLIGHT SIMULATOR

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ABSTRACT

A study was undertaken to investigate the feasibility of providing motion simulation with an in-cockpit device rather than an external motion platform. The conventional wisdom has deemed that it would not be feasible to provide the necessary stimulation of the vestibular apparatus because of insufficient excursion inherent in an in-cockpit device. This paper addresses that issue in light of recent research that begins to clarify this interrelationship between the visual and vestibular systems in the perception of motion. A novel approach is suggested which relies heavily on the coordination of the visual and vestibular systems. In addition, experimental protocols are suggested by which the approach can be verified. This study was originally performed for helicopter simulators but the technique is applicable to fighters as well and perhaps even to transport aircraft.

INTRODUCTION

Since motion is perceived through stimulation of several physiological receptor systems (visual, vestibular, haptic and auditory), many designers and users of flight training simulators have felt it was necessary to utilize platform motion systems to provide the vestibular and some of the haptic stimuli. This has, by no means, been a unanimous point of view. In fact, the subject has been controversial in the flight training community for quite some time.

The reasons for the controversy are manifold, not the least of which is cost -- including purchase, facilities and maintenance. Other factors are compatibility with certain visual displays, false cues in certain maneuvers, safety and reliability.

There is then a great deal of motivation to eliminate platform motion systems. It is our opinion, however, that in order to provide the appropriate motion stimuli, the platform motion system must be replaced with an adequate surrogate. This opinion is based in the recent research which indicates some vestibular stimulation is necessary for the proper percept of self motion. (11)

PLATFORM MOTION SYSTEMS

Motion platforms are difficult to justify in terms of the more obvious factors such as initial cost, safety, facilities, maintenance and life cycle costs but also in terms of the more subtle factors relating to integration with other systems and training value obtained.

The motion platform most widely used consists of a hydraulically powered six-post synergistic, computer-driven system designed to carry and provide motion cues to a cockpit that often includes a visual system with electronics and a display system and a pilot. Such a load requires a large, powerful, responsive, and safe system capable of providing onset and sustained acceleration cues that are synchronized and compatible with all other systems.

The initial cost of a typical motion system is $400,000. If a ten year life span at 16 hours per day and 250 days per year and 10% per year inflation rate is assumed and considering costs of spares, training, facilities, maintenance and the like, a total 10 year life cycle cost of $3.7 million is predicted using a life cycle cost model. This leads to a cost of $92.50/hour to operate the motion system.

The safety aspects of motion systems must be carefully considered because they use high pressure hydraulics and powerful rams to create the motion that drives the cockpit.

Many safety features must be incorporated to preclude damage or injury. This requires hydraulic and electronic safety systems, and more and better maintenance facilities which contribute to the complexity and cost. Although over the years the systems have a proven safety record and are documented to be safe under normal utilization, the mere power, function, and form of the system is intrinsically hazardous.

The difficulty does not end there, for the platform must be integrated with all other systems. The cockpit must be mounted on the platform and requires special access for cabling and personnel. A visual system, when used, must be mounted on the platform to avoid a great many problems encountered in floor mounting such as compensating visual for motion. This can become particularly difficult when a wide-angle visual system is used due to its size, configuration, and electro-mechanical constraints resulting from mounting a dome, projectors and servo-electronics on the platform such as in the VTRS system or collimated dislays such as in the ASPT system.

Even when the visual system is mounted on the motion platform, cue synchronization is by no means guaranteed between the visual system position cuing and motion platform acceleration onset and sustained cuing.

Vision is said to be the most important of all the senses in perceiving motion. While this may, in general, be true, it must be qualified. The eye is a position sensing device, thus the perception of self motion, from its input, is generated very slowly.

In a simulator, a wide-angle visual system provides stimulation of the eyes' peripheral sensors which results in a greater visual perception of motion. However, the perception delay is still significant.

In cases of low-frequency maneuvering in slow aircraft or slow maneuvering in fast aircraft, the delay may be acceptable.

However, previous research indicates that high-frequency disturbance-type tasks, abrupt failure or turbulence effects, or flight dynamics of unstable aircraft operating in specific modes, such as helicopter hover, visual-only cuing is not fast enough to generate what is deemed good pilot performance. Motion improves performance. [9]

Abrupt motions which generate large acceleration over a small position change, are sensed better when acceleration forces are provided to stimulate the vestibular sensors.

The vestibular sensors are basically acceleration sensors and (in a perfectly synchronized simulator or the real world) respond to the second derivative of position. Therefore, their cuing information is significantly faster than the visual position information.

With the vestibular system, the pilot can get advanced warning of a position change in less time and magnitude of position change than required with visual-only cuing. A motion platform, however, has limited cuing capability due to limited travel but as long as the acceleration cue is long and large enough, and the cue is synchronized with the visual, a faster cue is provided.

This is not very easy to do considering multiprocessor configurations, throughput lags, iteration rate effects, hardware response times and all the factors contributing to mismatch between the visual and the motion; while providing adequate cuing to achieve the desired purpose.

If we consider the task of synchronizing the platform and the visual systems, there are many considerations in specifying the platform performance. The platform must provide a range of acceleration cues of acceptable time duration and magnitude with subliminal acceleration washout within the platform excursion limitations while reflecting visual position magnitude. The throughput lags and computer, hardware/software lags must be within an acceptable range of the visual lags so as not to be unacceptably out of phase; and the high response high pressure hydraulic hardware should not respond to computer iteration rate stepping.

The existence of these cue synchronization problems is known to be a variable depending on magnitude and frequency of input as well as system design and has been quantitatively documented in a few cases. [3]

PSYCHOPHYSICAL ASPECTS

It is well known that the human perceives his motion through space by the integration of information, by the brain, from the transducers of several physiological sensory systems: visual, vestibular, haptic and aural. The manner in which the apparatuses of these systems operate is described in several sources. [1, 4, 5, 7, 8, 14, 15] In addition to these there are many other sources to which the reader may refer in order to obtain complete discussions of the sensory systems. This information is processed yielding a usually coherent perception of the motion environment. The perception is not always coherent because in some cases information is ambiguous and in others specific sensory information is absent.

An example of a perceptual ambiguity is the case of the familiar "railroad station paradox." In this instance, a person sitting in a train stopped at the station perceives relative motion with respect to an adjacent train as that train begins to move. His initial reaction is that the train in which he is a passenger is moving in the opposite direction of the train that actually is moving. Subsequently, however, he resolves this ambiguity on the basis of further perceptual information. Hence, he finally concludes that it is the other train that is moving.

This visual illusion is known as vection. Vection is the perception of self motion due to stimulation of the visual system particularly in the periphery.

An example of incoherent perceptual information arising from the absence of perceptual information or incorrect perceptual information would be an airplane making a coordinated turn in a cloud bank. If the pilot does not look at his instruments, he has no indication that the airplane is changing heading. This phenomenon results from the fact that due to the cloud bank, there is no visual perception of heading change and since, in a coordinated turn, the forces are balanced, there is no stimulation of the vestibular or haptic apparatus. In this case, there is no knowledge of heading change and the situation may never be resolved without additional sensory information such as visual information from the instruments.

The modern flight simulator with its wide-angle visual system, moving platform, G-seat, anti-G-suit system and vibration systems attempts to stimulate, to some extent, all of the above mentioned sensory systems. In general, motion base systems employ an onset cue with a washout to provide an initial stimulus to the vestibular system and haptic system. Subsequently, the visual system, relying upon the vection phenomenon, sustains the motion sensation. G-suits and G-seats, both stimulating the haptic system, are employed to augment the vection phenomenon for sustained motion and to provide some high-G cuing. Vibration systems are used to provide the high frequency (up to 40 Hz) oscillatory motion cues.

The major, as yet unanswered, question in flight simulation today is: "Is platform motion necessary in the presence of wide field of view visual systems?" One point of view states that since self motion can be induced visually, there is no need for platform motion systems. Another point of view is founded in the research of Young and others, which basically states that the onset of vection is hastened by the presence of vestibular stimulation. [11, 13] Brandt and others state that without vestibular stimulation the onset of vection can be of the order of 2 to 12 seconds. [2] However, with the addition of vestibular stimulation this onset delay was imperceptible. [21] These researchers have also found that the direction of the stimulus is more important than the magnitude. Implicit in this, of course, is the fact that the stimulus must be in excess of the perceptual threshold. Young offers, "Merely a slight platform displacement or seat motion in the appropriate direction may be sufficient to bring forth well developed vection." [12]

It is safe to say, then, that there is sufficient evidence that vection takes too long to develop in the absence of vestibular stimulation to be effective in the maneuvering environment. Secondly, vection is quickened by vestibular stimulation. Thirdly, small amplitude seat motion in the correct direction will quicken the onset of vection. The foregoing is encouraging, in that it appears to offer a suitable basis for justification of a motion seat in lieu of a motion platform.

CUING APPROACHES

There are three possible cuing approaches which could be investigated here. The first is to employ an in-cockpit device in an onset cuing mode as is commonly done with platform motion systems. In this mode, the seat would be used to stimulate both vestibular and haptic systems. Onset and washout drive logic would be employed in this case. A second approach is to employ the seat to stimulate solely the haptic system in a sustained cuing modality. The third approach is to use the seat to provide a very short duration, pulse-type cue in the appropriate direction.

Onset Cuing Approach

In order to provide onset cuing with washout, a substantial amount of seat pan displacement is required. For example, to provide a vertical onset cue for 0.2 seconds with a maximum acceleration of 1.2g and employing a linear washout which is below the indifference threshold given by Hoffman and Reidel as 0.1g, the excursion required would be 30.9 inches. [6] This is obviously too great for an in-cockpit device. It should be noted that shortening the duration of the cue will serve to reduce substantially the total displacement required. For example, if the cue duration is reduced to 0.1 seconds for the onset, the system excursion requirements are reduced by a factor of four.

Therefore, reducing the onset cue duration to 0.1 would enable the presentation of a 0.3g cue and associated acceleration washout in 0.63 inches of platform excursion. This would be feasible within the context of most existing G-seats and also be acceptable within the constraints imposed by the cockpit geometry. However, the cuing dynamic range would be small, i.e., from 0.1g to 0.3g. An onset cue of 0.1 seconds would be near the upper end of the time constant range of the otoliths, which is less than 0.1 seconds. (10)

Examining the rotational axes in the same manner, and considering a rotational velocity cue required of 20°/sec., it was found that this cue would require over 40° seat pan rotation and the resulting washout velocity of 10°/sec. is above the indifference threshold of 2°/sec. These values are based on a washout acceleration of 5°/sec.^{2} and a cue duration of 0.2 seconds. The 40°/seat pan rotation results in 5.28 inches of vertical displacement, assuming a 12 inch separation of seat actuators. As was the case for the vertical excursion case, the cue duration could be reduced and this would yield lower performance requirements. However, considering time constants of 1 to 10 seconds for the semi-circular canals, then a cue duration of 0.1 sec. would be small as compared to the time constant. (15)

It should be noted that linear cuing only was considered above and if non-linear drive models were developed, the situation could improve. However, it is unlikely it would improve to the extent required for credible simulation.

Haptic System Stimulation Approach

The question here is whether using a device like a G-seat to stimulate the pressure and muscle receptors of the haptic system would be a viable approach in the context of this investigation. The traditional application of G-seats in flight simulators has been to employ them together with platform motion systems to provide the sustained acceleration cues while the platform provides the vestibular stimuli via onset cuing. The sustained cues have been provided by altering the pressure distribution, across the back and buttocks, due to pilot weight and aircraft acceleration vector. The general contribution of haptic system stimulation is quite well recognized at this point. However, what is not known is the relative importance of the two stimuli in the perception of motion. Further, no research has been performed to differentiate the relative importance of the two stimuli on the development of vection. However, it is known that some elements of the haptic system have small displacement thresholds and relatively low time constants (Table 1). This leads one to believe they might be stimulated by a small excursion system.

TABLE (1)

Sensor	Displacement Thresholds*	Time Constant
Pacinian Corpuscles	10 microns	1-10 ms
Merkel's Discs	1-5 mm	1 & 30 s
Ruffini End Organs	--	1, 5, & 20 s
Muscle Spindles	--	80 ms

*These data from Borah, et al.

These data offer some reason for optimism in that the thresholds are very low for the cutaneous and subcutaneous sensors, hence pressure stimuli, from a variable contour seat pan, would aid in the perception of motion via direct perception and perhaps through the quickening of vection.

A G-seat type device altering the pressure distribution of the back and buttocks could be used in conjunction with some small onset device as discussed in the previous section. However, this adds complication to the system.

As stated, one related area which has not been pursued is the effects of haptic stimulation, in the absence of vestibular system stimuli, on the onset of motion perception induced by vection. However, Young states that tactile cues respond most rapidly to changes in pressure and signal any rapid changes in acceleration because of the consequent change in support force "They are the ideal first simulator cue for rapid onset." (12) This is borne out by the data of Table (1).

Pulse Cuing Approach

The Pulse Cuing approach has its justification in the research of several investigators who have indicated that the vection phenomenon is hastened with vestibular stimulation, (2, 11, 13) and also that the vestibular stimulation need only be a short pulse in the appropriate direction. (12)

While this approach might involve a multi-degree-of-freedom seat platform in the cockpit, it would have very small excursions. How many degrees of freedom are required must be determined by additional research. At least four degrees of freedom are required, the three rotational and vertical. It is probable that linear vection can be quickened with rotational vestibular stimuli, but this must be verified. Another advantage of this approach is that the software drive algorithm would be very simple. Also, since the excursions would be small, eyepoint motion would be small and hence dynamic mapping of the eyepoint would not be necessary. Because of the small excursion requirements a pneumatic system may satisfy the response requirements.

The vertical degree of freedom should also be capable of providing vibration cues in the range of 3 to 40 Hz.

SUGGESTED RESEARCH

In order to evaluate the validity of the candidate approaches further research is needed. The research falls into two categories, that which will provide more psychophysical data and that which will verify simulation concepts. Some examples of the first category are: Will haptic system stimulation alone hasten the onset of vection? Will rotational vestibular stimuli quicken linear vection? What are the required pulse characteristics, i.e., pulsewidth and range of magnitudes?

A problem with much of this research is that of finding an objective measure of the results. In this case, using visual nystagmus should provide the desired results. Other techniques are also available. One technique for obtaining quantitative objective measure of psychophysical phenomena is the method of evoked response. Much has been written in the literature about visual evoked potential (VEP) but to our knowledge, this technique has not been applied to determining the onset of vection, or for that matter other simulation research.

The second category of research is more simulation specific. Some examples of the kinds of research in this category are: employ a one-dimensional tracking task both with and without the pulse cue to hasten the onset of vection, which would be stimulated by an appropriate display. The subjects' performance in both cases would be measured and compared. The experiment should also be performed using an unconstrained single-degree-of-freedom rotational motion system in place of the pulse cue. The subject's performance on this task would then be compared with the other two conditions. Other transfer of training experiments may be performed as well.

Needless to say, subjective evaluations with experienced pilots must be performed as well, in order to ensure that the technique will gain acceptance in the user community. Also, experimentation with various drive algorithms is necessary. In the case of the pulse cuing approach, the only aspects of the drive algorithm to be considered are the magnitude, duration and direction of the pulse.

CONCLUSION

Of the three approaches suggested it appears that the option with the most promise is the pulse cuing approach. The onset cuing approach has very little expectation of success because of the limited stroke available. There is some question as to whether, even in large stroke motion platforms, an optimum drive algorithm has been developed. Hence, the degree of acceptability is very low for these systems. It is, therefore, unreasonable to expect that an in-cockpit device with much less stroke would ever be acceptable.

The second approach employing haptic system stimulation does have some promise but requires a substantial amount of research for this application. In addition, the effort to develop suitable drive algorithms would be extensive.

The pulse cuing approach is attractive in its simplicity as well as the reasonably high expectation of success it engenders.

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PROTOTYPE SPECIFICATIONS TO SUPPORT HIGH RESOLUTION-SENSOR SIMULATORS

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ABSTRACT

The Defense Mapping Agency is developing a follow on Prototype Product Specification for Digital Data to support High Resolution data requirements in the DoD. The computer hardware technology is growing faster than the software technology to enable simulators to portray realism. Both these technologies and the DoD requirements are growing much faster than DMA's ability to produce the digital products required for the multiple applications. The Prototype specification is an effort to narrow the gap of these technologies.

This paper will discuss the development of the High Resolution data Specifications; define and compare parameters of the current and Prototype data; describe the geographical area of coverage; and, discuss user evaluation and validation of the data content.

Introduction

The Defense Mapping Agency has been producing digital data since the early 1960's. This data was generally used to produce relief Maps. It wasn't until 1972 that DMA was directed to produce digital data to support an R&D effort to provide radar displays in simulators for aircrew training. A production specification for digital data for Radar simulation resulted in this R&D effort. This specification was published in 1974 and is called Digital Landmass system (DLMS). The DLMS product is composed of a Matrix of terrain elevations called Digital Terrain Evaluation Data (DTED) and Cultural data called Digital Feature Analysis Data (DFAD). DFAD predicts the radar reflectivity of the earth's surface. The DLMS program supports Weapons Systems Trainers (WST) and operational uses such as cruise missile planning, Firefinder, aircraft mission planning, etc. The DLMS Program requires millions of square nautical miles of DFAD and DTED.

In 1975 DMA was given the responsibility to produce all the Mapping, Charting and Geodesy (MC&G) digital data required by the DoD. With this responsibility it was necessary to insure that all users requirements were reflected in the specification. As experience and user feedback were received using the initial DLMS specifications DMA refined the specification to better support sensor simulation. The first revision of the specification was in July 1977, with three smaller revisions, changes 1, 2 and 3, in 1980-81, resulting in the current product specification. Some of the major changes in these revisions since 1977 are:

a. Standardization of feature descriptors -e.g., Surface Material Code (SMC) 3 Farm structures portrayed as point features.
b. Increase feature identification codes -e.g., from 57 to over 260.
c. Decrease minimum size for strong reflectors -e.g., Bridge.
d. Increase minimum size for poor reflectors -e.g., Desert areas.
e. Expansion of unique features -e.g., Railroad Gantries/Pylons.
f. Standardization of percent of roof cover descriptor - e.g., 0%, 10% and 30%.
g. Portrayal of permanent snow and ice.

Another change, 2nd Edition DLMS, is currently in coordination which will include the addition of LOC's (lines of communication).

PROTOTYPE PRODUCT SPECIFICATION FOR HIGH RESOLUTION SENSOR SIMULATION

In 1978 DMA received an Air Force request to supply digital data to support an out of the cockpit visual simulator. Until this request was received, DMA had only been supporting radar simulation requirements and the specification were designed for that purpose only. With the advent of visual requirements, it became obvious to DMA that a major revision to the digital data specification was required.

Investigations were begun to determine the data elements required for visual simulation. Discussions with various DoD users and contractors revealed that no one had the same requirement for MC&G support. Recognizing the importance of the next generation of specifications, DMA hosted a meeting at St. Louis in Sept 1978 for interested DoD users and contractors to take part in preparing a specification for visual simulation. Personnel in attendance represented Hq Strategic Air Command (SAC), Hq Military Airlift Command (MAC), Hq Tactical Air Command (TAC), Pacific Air Forces (PACAF), Naval Training and Equipment Center (NTEC), Aeronautical Systems Division (ASD), Engineering Topographic Laboratory (ETL), Rome Air Development Center (RADC) and both production centers of DMA, Hydrographic/Topographic Center (DMAHTC) and Aerospace Center (DMAAC). The first meeting resulted in a decision to develop a Prototype Specification for data which was designed to support high resolution sensor simulation including Visual, Synthetic Aperature Radar (SAR), Low Light Level Television (LLLTV) and Infrared (IR). The prototype data will be used to evaluate how well high resolution sensor simulation can be supported by an enhanced DLMS.

This paper covers only the planimetric (cultural and landscape) features. DMA believes that Standard Level I Terrain will be satisfactory for high resolution sensor simulation.

DRAFT SPECIFICATION

The next generation specification is one that must satisfy requirements for all services, therefore, DMA developed a policy on Future Data Bases to include the following major points:

1. Common data elements will be established for multiple applications.
2. The data will be stored in such a way as to permit multiple product generation.
3. The format will be designed to support evolving requirements.
4. In order to save critical manpower, DMA will produce to the most stringent requirements where multiple products are scheduled.

Utilizing this guideline and meeting with the various users and their support organizations, a prototype product specification was prepared and published in December 1979. Five areas in the continental U.S. were selected to be compiled to this specification and production was initiated.

SPECIFICATION CHARACTERISTICS

The Prototype Specification consists of geographically defined areas (manuscripts) which contain two separate levels of information. This information describes the geographic location and the associated descriptive information defining natural and man-made features on the surface of the earth (similar to current DLMS). Level V (for visual) which is similar to Level I DLMS, is comprised of relatively large geographically defined areas containing a description and portrayal of natural and man-made features presented in a standardized digital format. Level V data is designed to cover large expanses of the earth's surface; therefore, it is designed to contain a generalized portrayal of features. Level V is meant to support the generation of high detail by using Computer Image Generation (CIG) and Synthetic Break-Up (SBU) techniques. CIG and SBU are processes by which descriptions of large homogeneous areal features (regions) are used with computer software to break features into component parts. It is expected that these techniques will be employed by the user as required.

MAJOR DIFFERENCES BETWEEN LEVEL V AND LEVEL I

1. Level V includes more features.
   Level V specification includes all Lines of Communication (LOC) such as roads, railroads/powerlines, etc., and streams, lakes and ponds. Level I was developed for radar simulation and generally contains only radar significant features.
2. Level V utilizes microdescriptors
   Microdescriptors (feature attribute attachment) are multipurpose descriptors which describe additional (visual) characteristics of a feature. By using this information as the basis for statistically based feature generation, a more realistic breakup can be performed than by purely random means. Four microdescriptors were developed for Level V.
3. Level V has unique Surface Material Code for asphalt (SMC 14).
   Asphalt was included in SMC 9 in the DLMS specification.
4. Level V portrays isolated structures (SMC 4) ncluding composition structures that are not radar significant but are visually significant.
5. Feature Area Code (FAC) #1, of Level V is the most predominant background feature in the given area. In the DLMS specification, feature #1 is always normal soil.

6. No feature separation criteria is included in Level V. DLMS has an areal feature separation of 500 feet. Level V, without this separation, can be utilized to generate more realistic scenes by showing continuous streams/features regardless of width.

7. Level V portrays wood obstructions 50-150' high. DLMS portrays only those obstructions over 150'.

TERRAIN ANALYSIS DATA

In the fall of 1981, DMA was asked to expand the Level V format to accept the data elements of terrain analysis using DMAHTC's Draft Production Specifications for the Tactical Terrain Data Base (1:50,000) dated September 1981. DMAAC created three additional microdescriptors and coordinated with HTC and Army personnel on common data elements. An area in Ft. Lewis, Washington was selected as a test. In order to compare the density of data and evaluate content, Level V and Level V enhanced with terrain analysis, were both compiled over Ft. Lewis.

Figure 1 is a portion of the manuscript of the Ft. Lewis area compiled to the current 1977 DLMS specifications. Figure 2 is the same area compiled to the Level V specifications and Figure 3 is the Terrain Analysis Specifications. The correlation of the data from these three specifications is extremely close. Level V is compatible with Level 1 but defines the features in more detail. The terrain analysis manuscript is compatible with the Level V, and also portrays much more detail. Figure 4 shows the Level V and terrain analysis data merged and plotted into a manuscript for both Air Force and Army programs. This is the new Prototype High Resolution Specification capable of multiuse. It has common data elements and can be expanded to accept new requirements.

DATA DENSITY

The density of the data, as well as the resources required to produce Level V or enhanced Level V, can increase 3-5 times over the current Level 1. In order to handle this magnitude of data, and have a specification that is as flexible to support multiple products, three additional microdescriptors are required. These microdescriptors plus the four developed for Level V can be used when necessary to further define a feature to satisfy a specific product requirement. The available microdescriptors are as follows:

1. Vertically composite feature (e.g., tower on a building).
2. Homogeneous area descriptor (e.g., residential area).
3. A pattern definition (e.g., street or field pattern).
4. Combination of 2 and 3.
5. Vegetation
6. Transportation
7. Surface Drainage

Figure 5 will be used as an example of data stored on a microdescriptor. For purposes of this example, feature number 97 will be utilized (Table 1).

The Feature Analysis Data Table contains all the data recorded by the analysts for this feature. The top line is the primary descriptive information which is determined for all features (Table 2) and the succeeding lines will be microdescriptor information, if required. Feature number 97 is a forest area and requires the microdescriptor number 5 to satisfy the user requirement in this geographic area. (Table 3)

PROTOTYPE TEST AREA

The five geographic areas selected by the users for testing the Level V specification are as follows:

Area 1 - A rectangle around Norfolk, VA and NAS Oceana containing approximately 450 SNM.

Area 2 - A 15 mile radius circle centered on the main runway at Barksdale AFB, LA (700 SNM).

Area 3 - An area around Little Rock AFB, AR containing 1850 SNM.

Area 4 - 100 SNM over New York City covering Manhattan, Island.

Area 5 - Fallon, Nevada. An area of approximately 1400 SNM.

These five areas will provide the user all types of culture and landscape information from large cities to desert areas and allow them to evaluate the adequacy of the specification.

An additional area, No. 6, covering Ft. Lewis, Washington, has been produced containing both Level V and terrain analysis data. This area contains 250 SNM.

Other areas are being compiled to the terrain analysis enhanced Level V specification and should be completed by the end of 1982.

TABLE 1

FEATURE ANALYSIS DATA TABLE

96	2	4000		4	1		3		4	56	10					2	
96	1	10		32	10												
96	5																1
97	2	953112							18							1	
97	5	3	9	11		4	2	0	0		3	1	1	2	8		
98	2	4000		4	1		3		4	56	10					2	
98	1	10		32	10												
98	5																1
99	2	953112							18							1	
99	2	3	9	11		4	2	0	0		3	1	1	2	8		

CODED DESCRIPTIVE DATA FOR FT. LEWIS, WASHINGTON

TABLE 2

FEATURE ANALYSIS
DATA TABLE (FADTP)
PRIMARY DESCRIPTOR

- FAC NUMBER-97
- FEATURE TYPE-2
- FEATURE IDENTIFICATION CODE-9531
- SURFACE MATERIAL CATEGORY-12
- PREDOMINANT HEIGHT-18
- NUMBER OF MICRODESCRIPTORS-1

TABLE 3

VEGETATION
MICRODESCRIPTOR #5

FAC NUMBER-97
MICRO TYPE-5
CANOPY (SUMMER) CLOSURE-3
STEM DIAMETER-9
STEM SPACING-11
VEGETATION ROUGHNESS FACTOR-4
UNDERGROWTH-2
TREE CROWN DIA-0
HEIGHT OF LOWEST BRANCH-0

SPECIFIC TYPE-3
QUALIFIER-1
STATE OF GROUND-1
DEPTH OF SMC ROUGHNESS-2
(MED & HEAVY TANKS)-8
ROUGHNESS (LARGE WHEEL VECH)-0
ROUGHNESS (WHEEL VECH)-0
ROUGHNESS (FOOT TROOPS)-0
CLOSURE RATED CONE INDEX-0

Figure 1 - Current DLMS Level I

Figure 2 - Level V

Figure 3 - Terrain Analysis

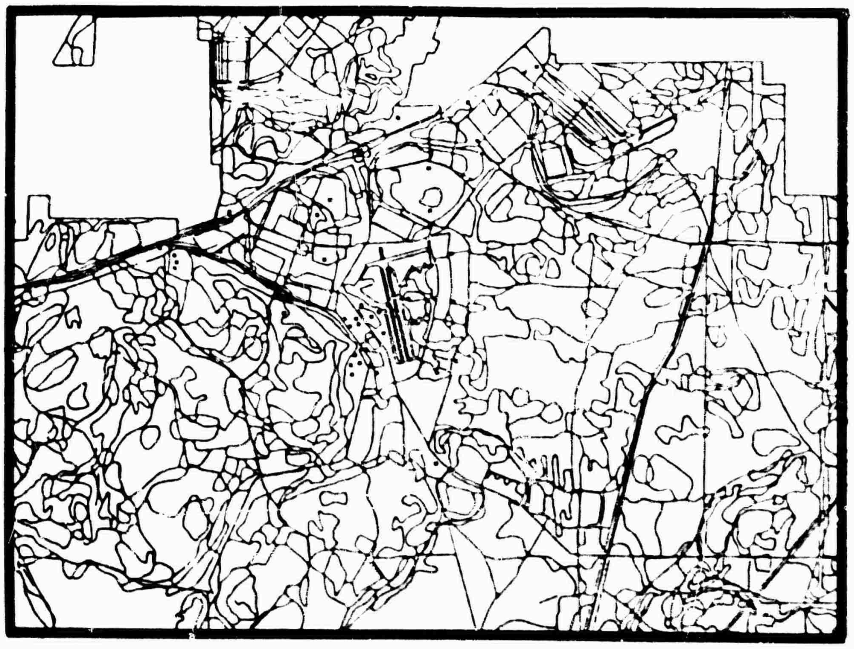

Figure 4 - Level V and Terrain Analysis

Figure 5 - Ft. Lewis, Washington Manuscript (Areal Features)

SUMMARY

Six domestic areas have been compiled using the new specification. These areas total approximately 5000 square nautical miles. The areas will be made available to the users for test and evaluation of the data content. DMA will be requesting comments on the specification as to the ability to satisfy current and future requirements. ASD is working with interested simulator contractors and is soliciting their comments. The Federal Republic of Germany and the United Kingdom have also indicated interest in the new specification. A copy of the specification and a magnetic tape of the Ft. Lewis area is being provided these NATO countries for their evaluation and comments.

An evaluation plan is presently being developed by a committee headed by HQ DMA with members from each service, DMAHTC and DMAAC. The purpose of this plan is to establish milestones to insure that all comments are considered in the revision of the final specification. The goal is to have a specification that will support an all purpose multiuse digital data base in 1985.

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1. Defense Mapping Agency; 1977; "Product Specification for Digital Landmass (DLMS) Data Base" St. Louis AFS, MO.

2. Defense Mapping Agency; 1979; "Product Specifications for a Prototype Data Base to Support High Resolution Sensor Simulation," Washington, DC.

3. Faintich, M. B.; 1981; "Increased Sensor Simulation Capability as a Result of Improvements to the Digital Landmass System (DLMS) Data Base." Proceedings of the Image Generation/Display Conference II, June 10- 12, 1981, Scotsdale, Arizona, pages 181-196.

About the Author

Mr. Ronald J. Pierce is a Physical Scientist at the Defense Mapping Agency Aerospace Center St. Louis AFS, MO. He is presently responsible for the development of a multiuse Digital Data Base for the DoD in the past 1985 time frame. He has had extensive experience in collection of Digital Terrain Elevation data, target derivation, chart compilation and various programs in the fields of geodesy and photogrammetry. He received his BS degree from the University of Tulsa in Geology and graduate studies in geodesy at Ohio State University.

AD P000189

SIMULATION METHODS FOR HIGH RESOLUTION ANALYSIS SONARS

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ABSTRACT

Training simulators for modern analysis sonar and sonobuoy processing equipments demand high accuracy target generators for maximum training value. The essential requirement is for high frequency stability and resolution and a wide range of frequencies, whether these be representing discrete signals or forming modulating envelopes. This requirement is due to the high resolution of such sonars where any instability or steps in the generated signals show on the analysed signal and can confuse trainees. A "Passive Acoustic Target" module has been developed which satisfies the above requirement. The paper describes the features and the method of realisation of the modules to satisfy the requirement.

INTRODUCTION

Requirement

The equipment described in this paper was designed and produced to meet a training requirement identified by various users. The requirement was to produce sonar simulators for:

1. Advanced Operator Training in the use of sophisticated analysis sonars and sonobuoy processing systems.

2. Combined Tactical Training at an advanced level.

The level of instruction which was to be given was identified by the potential instructors as requiring the use of operational equipment which would respond to the operators controls with a high degree of realism. The use of facsimile equipment was considered not to be acceptable for the high level of training to be done.

It is therefore clear from the above constraints that it was necessary to produce a system which would stimulate sufficient of the operational equipment to satisfy the requirement. It will be appreciated that in producing such a stimulus to operational equipment, which is going to produce long term hard copy of the analysed signals, both long term and short term instability need to be absent in these analysed signals except for ones which form a part of the target vessel signature, and the resolution of the generator must be high so that steps in the analysed waveform cannot be seen.

Stimulation Signals

The basic method of producing a stimulation signal for a sonar system is well known and basically consists of:

1. Generation of Target Produced noise.

2. Generation of background noise to represent the environment in which the target exists.

3. The combination of these two components at the correct level at the transducer of the simulated sonar taking into account source strengths and propagation losses.

4. Processing the signals to represent those parts of the sonar system which are not used in the simulator.

5. Injection of these combined and processed signals into the operational equipment at the chosen point.

The only item to be considered in this paper is the generation of the target produced noise.

PASSIVE ACOUSTIC TARGET (PAT) MODULE

PAT Components

A block diagram of the PAT module is shown in Fig.1. The components of the PAT are:

1. An Intelligent Interface Module (IIM) consisting of a microprocessor with associated PROM and RAM to which data from the main simulation computer is sent defining the targets to be generated. This data is processed to generate the control signals and data for the remainder of the module.

2. An Inverse Fourier Transform Module (IFTM) which generates accurately the required waveforms. This is described in detail later.

3. Analogue processing circuitry utilising the accurately generated waveforms to produce the final Vessel Radiated Noise (VRN).

It is not intended to discuss the IIM as it is a standard microprocessor system, however the operation of the IFTM and the use of the signals to produce the VRN form the remainder of this paper.

IFTM

Capability

The module is capable of generating a total of up to 256 spectral lines, each of which is independantly controllable in frequency, phase and amplitude. The frequency resolution with which components may be set is 0.0125Hz or better, and all component frequencies are derived from a common crystal controlled oscillator.

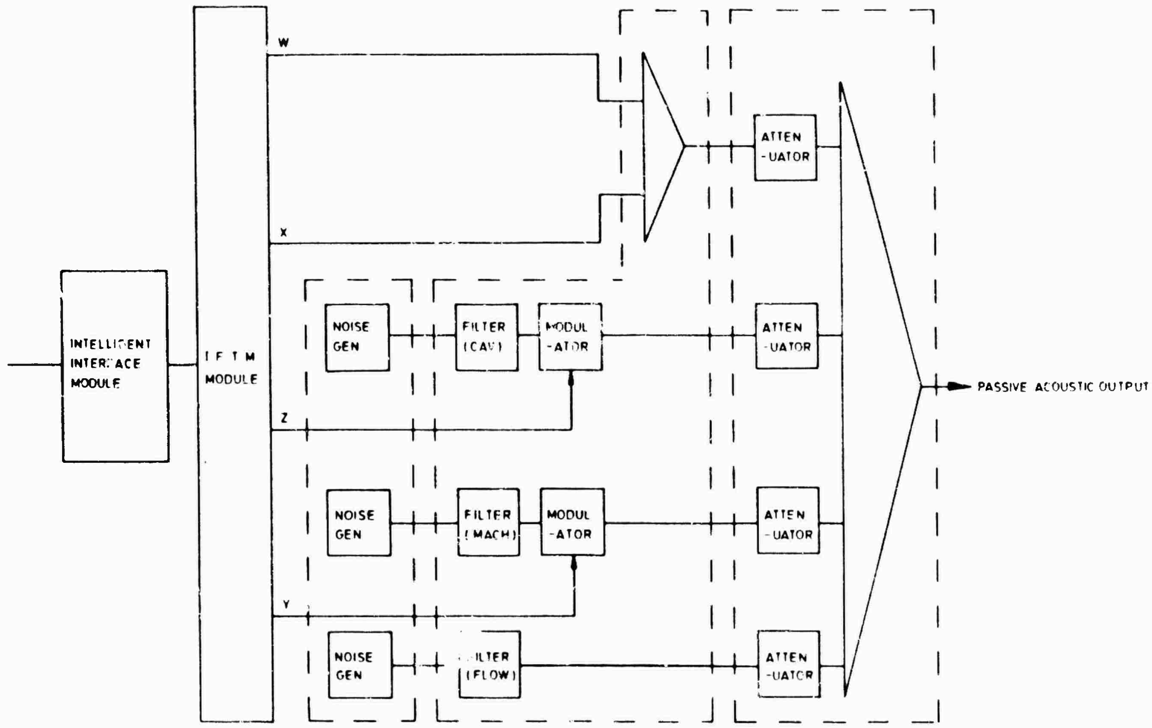

FIG 1 PASSIVE ACOUSTIC TARGET MODULE

Since the module is controlled by frequency data it is possible for controlling programs to take into account any modification to the spectrum of the radiated noise which may result from propagation through the water. The use of frequency data, rather than a time/amplitude sample technique, allows both harmonically related and unrelated components to be generated simultaneously. Each spectral line is independently controllable in frequency, amplitude and phase but may be set to be a harmonic of another component if required by setting the frequencies as close as possible and phase-locking. This generation technique rather than the amplitude sample one also means that since the samples are computed by the module as required in real time it is possible to generate a very low frequency component (e.g. 0.012 Hz) at the same time as high frequencies (e.g. 3KHz) at the same output.

The module produces four analogue output waveforms, referred to as W, X, Y, Z.

One output (W) is capable of producing 64 components up to a frequency of 2KHz. If the maximum frequency required is greater than 2KHz and the W output is limited to 32 components the maximum frequency is increased to 4KHz. Fig.2 shows the summary of the capabilities in this format and this format is assumed for the remainder of the paper.

An overall block diagram is shown in Fig.3. and Figs.4-7 show more detail.

Note	Output	W	X	Y	Z
2,5	Number of components	32	64	64	64
1,2	Frequency Range, Hz	0-4K	0-1.6K	0-400	0-400
2	Frequency Resolution, Hz	0.0125	0.00625	0.0015625	0.0015625
	Frequency Accuracy	Crystal controlled-better than 0.01%			
	Amplitude Control Range	>50 dB			
	Amplitude Control increment	<1.02 dB to -47 dB, <2 dB to -54 dB			
	Phase Control Range, deg.	0 - 360			
3	Phase Control Increment, deg.	1.4			
4	Unwanted sideband level with respect to full output	Better than -50 dB for o/p frequency <1.5kHz. Better than -40 dB for o/p up to 4kHz		Better than -50 dB	

NOTES

1. The module is capable of generating frequencies up to 6.4 kHz, 3.2 kHz, 800 Hz and 800 Hz respectively at outputs W,X,Y,Z. However, above the ranges quoted the wanted signal amplitude falls and the unwanted sideband level rises.

2. The module is able to generate, simultaneously, up to the stated number of components at any integral multiple of the stated resolution, within the stated Frequency Range.

3. Phase control accuracy deteriorates at high frequencies and is subject to some limitations.

4. The principal unwanted sidebands are at frequencies 13.1 kHz $\pm F_W$, 6.55 kHz $\pm F_X$, 1.64 kHz $\pm F_{Y,Z}$ for wanted frequencies F_W, F_X, F_Y, F_Z at outputs W,X,Y,Z repectively.

5. Each component may be either a sine wave or a square wave. In the latter case the highest harmonic component frequency will correspond approximately with the maximum of the frequency range quoted.

FIG.2 INVERSE FOURIER TRANSFORM MODULE CAPABILITY

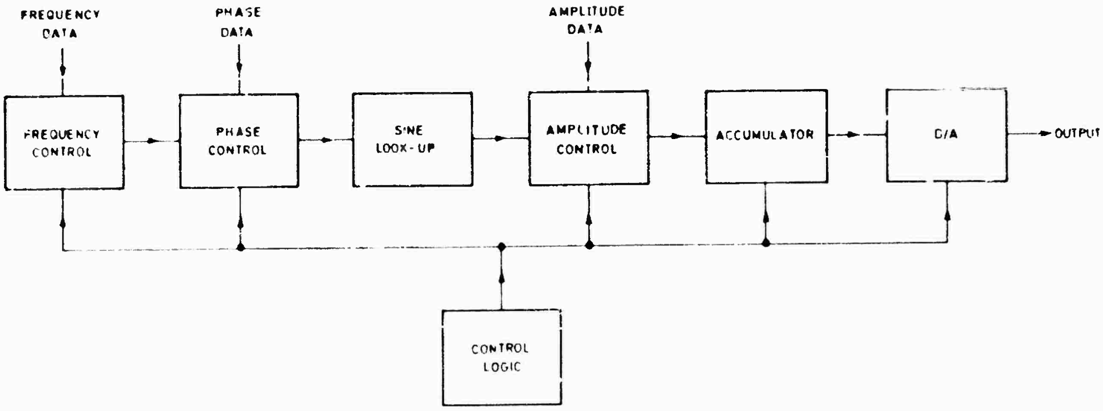

Fig.3 INVERSE FOURIER TRANSFORM MODULE-
OVERALL SYSTEM BLOCK DIAGRAM

Realisation

Overall Description (Fig.3)

Data for the 32 + 64 + 64 + 64 components of waveforms W,X,Y,Z respectively are loaded into RAM's under program control. The loading is interleaved with reading of data.

At fixed (crystal controlled) intervals the module computes amplitude samples for the four outputs W,X,Y,Z. Each sample comprises the sum of the samples computed for each of the constituent components, which are computed serially.

The computations of samples for the four outputs are interleaved. Each 80 microseconds, approximately, the module computes a full sample for Waveform W (32 components), half a sample (32 components) for Waveform X, and one quarter of a sample (16 components) for Waveform Y or Z. Thus a full sample of W is computed in one pass, a full sample of X in two passes, and a full sample of Y and Z in eight passes. The computation rate is about one component sample per microsecond.

The computation of one component comprises:

(i) Add the content of the frequency store to the previous phase-angle and store the new data.

(ii) Add the initial phase to the new phase angle.

(iii) Look up the sine of this phase-angle.

(iv) Multiply the sine value by the mantissa of the amplitude.

(v) Shift the result by the exponent of the amplitude.

(vi) Add the result to the contents of the accumulator.

Frequency Control (Fig.4)

Frequency control data for all components is entered into the Frequency Store under program control.

On each pass, data for each component is extracted from the store and added to the previous phase angle for the relevant component from the Phase Angle Store. The new phase angle is then output via the Phase Control to the Sine Look-up, and the new phase angle replaces the previous one in the Phase Angle Store.

Thus, on each pass, the Phase Angle (for a given component) is incremented by the "Frequency". The scaling is so chosen that a Frequency of 1 increments the Phase Angle through a full cycle in 2^{20} passes, which takes 80 secs. for output W, 160 secs. for output X and 640 secs. for outputs Y and Z. The corresponding frequency resolutions are thus 0.0125Hz, 0.00625Hz and 0.0015625Hz.

The phase-angle register can be reset to zero by a control from the Phase Control subsystem, and it can also be held at the phase value of the preceding component by a control from the Phase control sub-system.

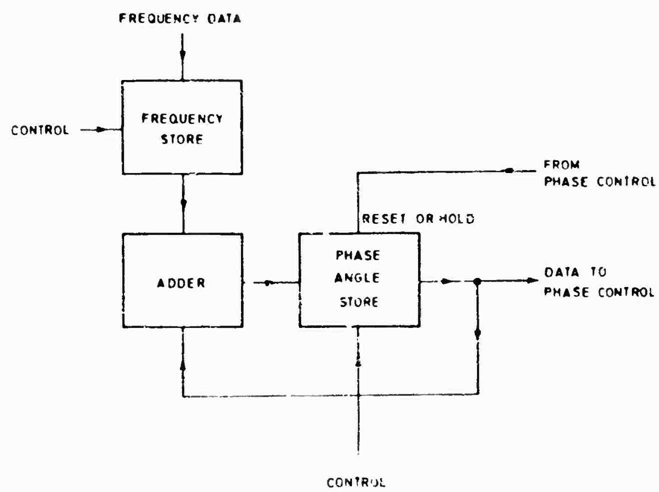

Fig 4 FREQUENCY CONTROL

Phase Control (Fig.5)

Initial phase angles are loaded into the initial Phase store under program control.

On each pass, the Initial Phase for each component is read from the store at the same time as frequency data is added to the phase angle from the Frequency Control sub-system.

Each time a component sample is computed the sign of the phase angle is examined, and if it changes from negative to positive the cycle count for that component is incremented. The cycle count is compared with the stored Harmonic Number for that component and when equivalence occurs, and if a marker bit (Mk1) is set in the control data to indicate that the component is the reference for a harmonic series or modulated wave, the control logic goes about resetting the phase-angles for the other components of the group as they are computed. The other components of the group are identified by another marker bit (Mk2). The resetting of components with MK2 set continues until another Mk1 is seen. (This could be the same Mk1 that started the process, seen on the next pass).

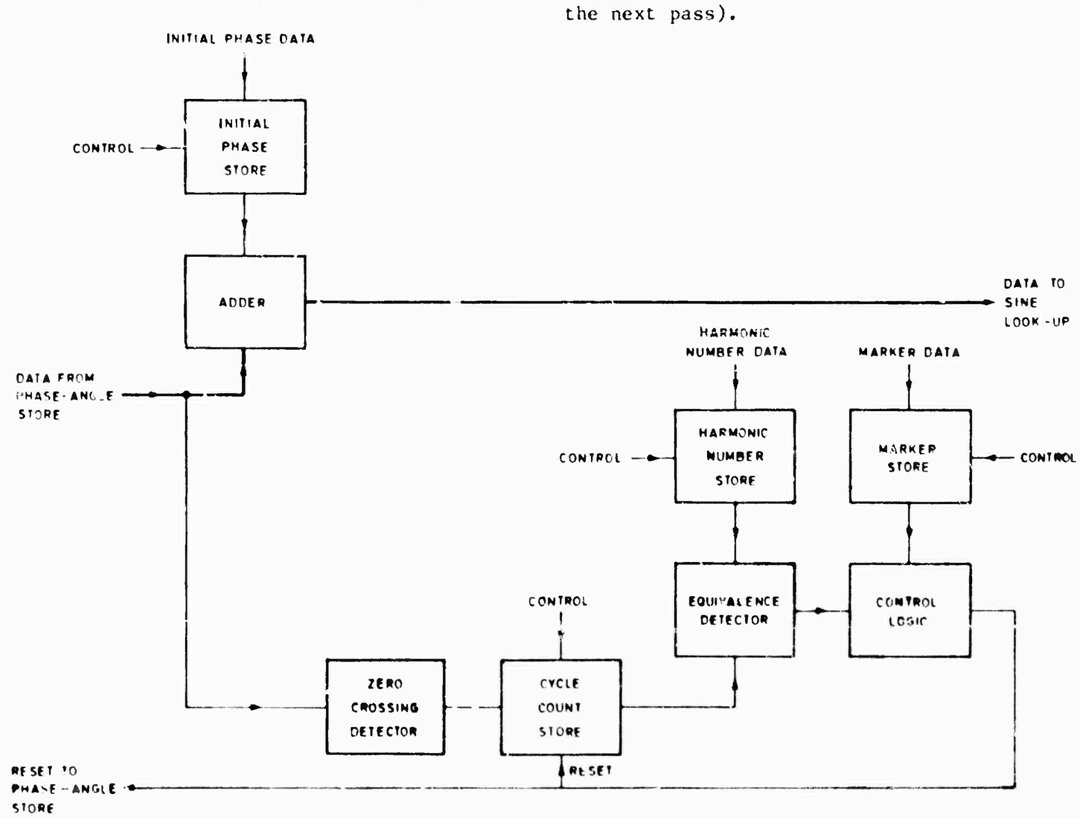

Fig 5 PHASE CONTROL

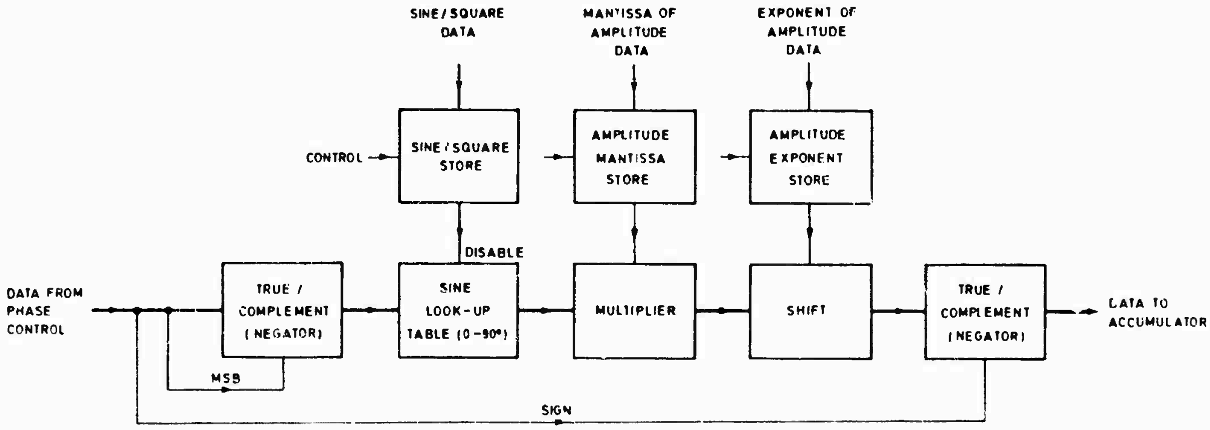

Fig 6 SINE LOOK-UP AND AMPLITUDE CONTROL

Sine Look-up and Amplitude Control (Fig.6)

The most significant bit of the phase-angle data represents 180°, and is used as the sign bit. The next bit represents 90° and is used to complement the less significant bits in the second and fourth quadrants. The sine table represents angles from 0 to 90°.

The sine value from the look-up table is then multiplied by the mantissa of the Amplitude data. The result is shifted left (to positions of greater significance) by the exponent of the Amplitude data.

The data is then negated if the sign bit is set.

If a marker bit is set in the control data, the sine table is disabled and gives an output of 1. Thus a square wave (± 1) is generated for any component which has this marker bit set.

Accumulator and D/A Conversion (Fig.7)

Components of a waveform sample are added in the accumulator. The accumulator register is first cleared and successive components are then added to the register contents. When the sample is complete (i.e. all components have been added) the accumulator register content is transferred to the D/A Register and the accumulator cleared again.

Multiplexing

The system as outlined is multiplexed between four outputs, W, X, Y and Z.

On each pass (80 S) 32 components of W, 32 components of X and 16 components of either Y or Z are computed and separately accumulated. A complete sample (32 components) of W is thus computed on every pass, two passes are required for a full sample of X, and 8 passes are used to accumulate full samples of Y and Z. When the complete samples have been accumulated they are transferred to the appropriate D/A register and the accumulators reset.

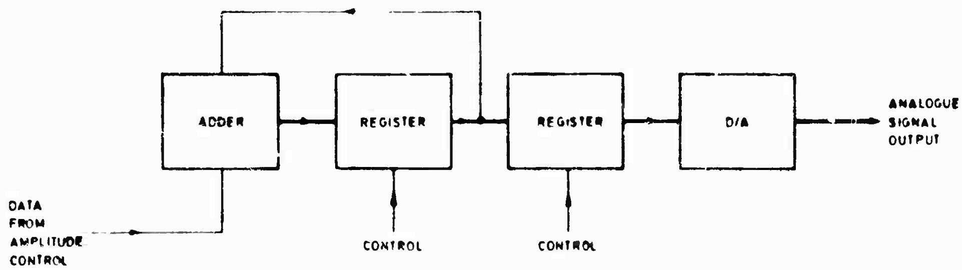

Fig 7 ACCUMULATOR AND D/A CONVERSION

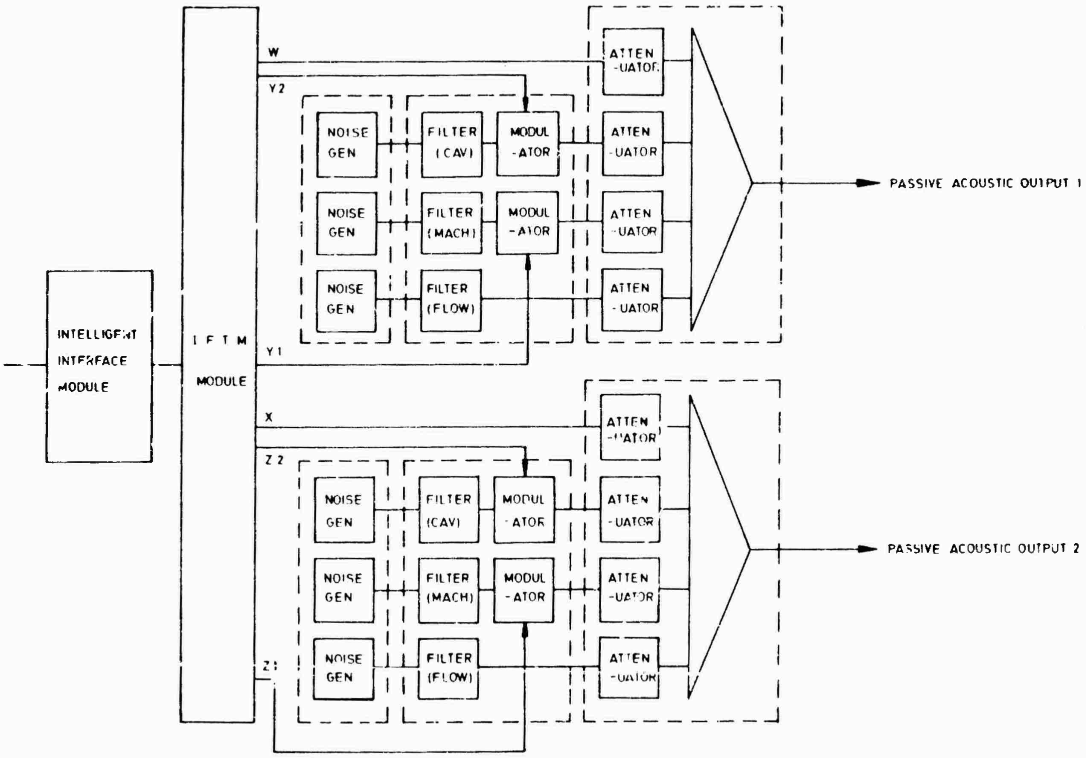

FIG 8 DOUBLE PASSIVE ACOUSTIC MODULE

Utilisation of Generated Waveforms

Fig.2 shows the utilisation of the generated waveforms to produce the composite VRN. The W and X outputs form the discrete frequencies generated by the target. The Y and Z outputs are used to modulate suitably filtered noise to represent cavitation and machinery noises. Unmodulated flow noise is also produced in the module. These components are then added together in the correct ratio by use of attenuators and a summing amplifier to form the complete VRN for use in the simulators.

Optional Alternative Generated Waveforms

Several options are available for the IFTM but the major use is to divide the Y and Z outputs into two separate outputs (Y1, Y2, Z1 and Z2) each with 32 components available. Hence it is possible to configure the module to produce two target VRNs with W and X providing the discrete components for each target and with Y1 and Y2, Z1 and Z2 forming the modulating signals. This obviously halves the number of lines available to each target but nevertheless produces a good target model. The modulating signals obviously have to modulate separate noise sources and separate flow noise is also required. This configuration is shown in Fig.8.

ABOUT THE AUTHORS

MR. J.A.H. SHAW is a Senior Systems Designer in the Training Simulators Group of the Cheadle Heath Division of Ferranti Computer Systems Ltd. where he is engaged in the system and module design of training simulators, mainly in the sonar field, for the British and other armed services. He graduated with an Honours B.Sc degree in Physics from the University of Manchester, England, and joined the guided weapon division of Ferranti Ltd. where he worked for a number of years on radar guidance systems for missiles, including the successful Bloodhound 2, before moving on to sonar simulation.

DR. T.J. HUNTER is Head of Design in the Training Simulators Group of Ferranti, Cheadle Heath. He is responsible for the System and Module Designs of all the training simulators produced by the group. He graduated with an Honours B.Sc degree in Electrical and Electronic Engineering from the University of Manchester where he subsequent obtained an M.Sc and Ph.D. for research into the simulation of multi-access computer systems. He then joined the Training Simulator Group of Ferranti and has been involved in most aspects of the production of simulators.

RANGE-DEPENDENT OCEAN ACOUSTIC TRANSMISSION LOSS CALCULATIONS IN A REAL-TIME FRAMEWORK

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ABSTRACT

Most anti-submarine warfare (ASW) trainers for either airborne or seaborne platforms require the simulation of ocean acoustic transmission loss to model the submarine signals received by sonobuoys or towed/hull arrays. Current trainer software usually employs transmission loss calculations based on acoustic theories which assume the ocean environment to be range-independent. That is, these theories assume that such variables as water depth and the sound speed profile (ssp) do not change along the path of acoustic transmission. Although such ocean modeling is not realistic, the final calculations have often been acceptable due to their high predictability.

With operational fleet equipment gaining in sophistication, the ocean acoustic software which stimulates this equipment must be refined. The introduction of range-dependent transmission loss calculations is one of the most important refinements. However, the associated theoretical problems are complex, and their solutions are difficult to implement practically, especially in simulators that require real-time software.

This paper discusses some of the complications that range-dependent ocean acoustic modeling introduces and uses a prototype model, the Multiple-Profile Configuration (MPC) Ocean Model, developed by the Link Simulation Systems Division of the Singer Company, to present specific methods of resolving these complications.

The MPC Ocean Model includes both off-line and on-line modules. The former pre-calculates those databases that depend only on the gaming area to be used, and the latter calculates, in real-time, the transmission loss of specific range-dependent acoustic paths. The on-line module includes such features as selective ray tracing for deep ocean calculations, normal-mode calculations for shallow ocean areas, and simulation of seamount shadowing. All are used within the framework of range-dependent sound speed, water depth, and bottom type. This model is presently incorporated into a P3-C Orion, Weapon System Trainer.

INTRODUCTION

Tactical considerations of anti-submarine warfare (ASW) lead to a variety of complicated operational scenarios. A simplified example is depicted in Figure 1, where emphasis is placed on the related ocean acoustics. A given scenario may involve many airborne and seaborne platforms trying to locate, evade, or attack each other. Applications of underwater acoustics play a major role in the first two of these objectives. Consequently, ASW trainers must simulate ocean acoustic phenomena, and of course, they must do so in real-time to be effective. Thus, in addition to various non-acoustic systems (e.g. radar, position keeping, magnetic anomaly detection), such trainers also include many software/hardware systems in order to simulate the relevant acoustics: signal generation, transmission, reception, analysis, and display.

Figure 1. ASW Ocean-Acoustic Scenario.

This paper focuses on the real-time software modeling of ocean acoustic transmission. The prototype for this discussion is the Multiple-Profile Configuration (MPC) Ocean Model developed by the Link Simulation Systems Division (Link SSD) of the Singer Company, and which is presently incorporated into a P3-C Orion aircraft trainer. The MPC Ocean Model is a software package which simulates the acoustic transmission loss for target signals received by passive, omnidirectional sonobuoy systems. (This calculated loss is input to a digital signal generator; appropriate target characteristics are incorporated, and the output stimulates the on-board acoustic data processor providing the displays at the aircraft sensor stations.)

The MPC Ocean Model has as its design basis a combination of U.S. Navy research and development (R&D) transmission loss models, a feature it shares with most other trainer-based models. The reason is twofold. First, the major customer for ASW trainers is the Navy, whose trainees and fleet operators are briefed in the areas of acoustics using calculations made by Navy research models. Second, the Navy scientific laboratories have spent forty years performing basic research and generating most of the consequent computer models. They have tested and refined their theories by numerous at-sea experiments. Due to the unwieldy ocean environment and the large number of uncontrollable variables, the theory-experiment cycling process has been slow and expensive. Thus, it is cost-effective for trainer-configured models to utilize the fruits of this labor. It must be remembered, however, that whereas the various research models may execute for several seconds or minutes to obtain one calculated result, their trainer-based counterparts must run in real-time, which is typically less than one second. This engineering problem is overcome by using various approximations to the full theories, by employing table look-ups of pre-calculated databases, or by combinations of these approaches.

The past decade has seen ocean acoustic research modeling rise to a relatively high level of theoretical and computational sophistication. Similar advances are being realized in the software/hardware of the newest on-board Navy fleet operational systems. Hence, the detailed effects of the ocean environment on acoustic transmission are now better understood and are also becoming more recognizable. This presents a rather complex problem in the design of realistic ASW simulation systems, because their level of sophistication must parallel the fleet systems. To get enhanced transmission loss calculations in real-time, considerable computation power is required. As an example, out of four computers comprising the above-mentioned P3-C trainer, one computer is entirely dedicated for the MPC Ocean Model. This is notable because transmission loss is only part of the acoustics picture, and there are also many non-acoustic systems to be simulated. On previous ASW trainers, much less sophisticated transmission loss models have occupied substantially smaller portions of similar computers.

PREVIOUS DESIGN APPROACHES

Perhaps the best known R&D transmission loss model is the Fast Asymptotic Coherent Transmission (FACT) model,[1,2] further distinguished by its use at Fleet Numerical Oceanography Center (FNOC) to generate standard aircrew ASW briefing packages. These Acoustic Sensor Range Prediction (ASRAP) packages are used by ASW instructors/trainees as well as the fleet. Each package includes plots of transmission loss versus range for various frequencies and sensor depth combinations. For example, for the four standard frequencies (50, 300, 850, 1700 Hz) and four combinations of target/sonobuoy depths (each being "shallow" or "deep"), the ASRAP package for a given ocean area includes sixteen transmisison loss curves. These curves sufficiently cover the FACT-generated loss data, for FACT treats the given ocean area as being environmentally range-independent. This means that the water depth is fixed (flat-bottom ocean model) and the sound speed profile and bottom type remain constant with range.

With such precedence, it is no wonder that the FACT model figures heavily in the design bases of most previous ASW simulators. In particular, P3-type simulators have, for 10 years, employed a simple table look-up approach. The on-line model linearly interpolates/extrapolates the pre-calculated FACT loss data for the actual frequencies, ranges, and depths of interest. The resultant losses are not necessarily correct, but they provide the advantage of being very accurately predictable, with smooth transitions between ASRAP values. Link SSD-developed submarine trainers of younger vintage employ FACT directly on-line, although modified and re-coded for real-time. This approach significantly increases the required computer power, but it produces agreement with FACT at all frequencies, ranges, and depths.

Other trainers (e.g. the S3-A Viking aircraft series) also use a direct calculation approach. A simplified ocean environment is modeled, using standard R&D-based techniques approximated to yield real-time transmission loss calculations. The classically observed effects are modeled, sometimes better than FACT, but with the disadvantage of not matching that model.

What all of these approaches have in common are their exclusion of range dependence in the ocean environment. Consequently, their results are predictable, but they are often inadequate for modeling a realistic ocean area. However, with the mutual increase in computer power and research model capabilities, range dependence can now be incorporated into the simulation computer complex, as it should be with fleet equipment gaining in sophistication.

RANGE-DEPENDENT TRANSMISSION LOSS

Background

The ocean environment is nonhomogeneous in every respect. Although the parameters that vary with range are many, those parameters having an appreciable effect on acoustic transmission loss have been identified and studied by numerous scientists. These parameters are illustrated in Figure 2. The short-dashed lines shown emanating from the target in the figure are acoustic rays. Ray tracing (about which more will be said later) is one method, fortunately a very graphic one, of analyzing how emitted signals are transmitted to an underwater receiver. It is used by a number of research models including FACT, and is the basis for the deep ocean calculations of the MPC Ocean Model. Ray tracing is easy to extend theoretically to include a range-dependent environment; this has been accomplished for example, by the following research models: RAYWAVE II [Naval Ocean Systems Center (NOSC)],(3) TRIMAIN [Naval Research Laboratory (NRL)],(4) and GRASS: Germinating Ray Acoustics Simulation System (NRL).(5) To implement range-dependent ray tracing practically, however, is difficult, especially in simulators that require real-time software.

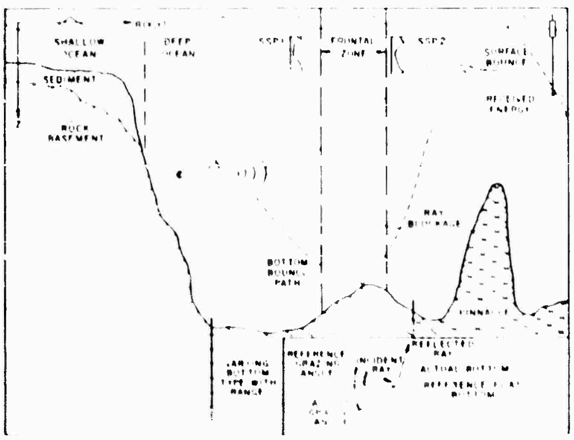


Figure 2. Range Dependence in the Ocean Environment.

Figure 2 shows graphically some of the consequences of range dependence for ray tracing. As in the effect that pinnacles (or seamounts) may have of blocking further transmission of an intercepted ray. Also, note how the direction of energy transmission changes after an encounter with the ocean bottom. Ray tracing assumes that incident rays are specularly reflected off of the ocean bottom. Hence, a change in the bottom slope yields an effective change in the incident grazing angle, thus producing a reflected ray that is dependent on the bottom slope (see inset in Figure 2). The effect that a sloping bottom versus a flat bottom may have on transmission loss is dramatically illustrated in Figure 3, which was generated by the GRASS model.

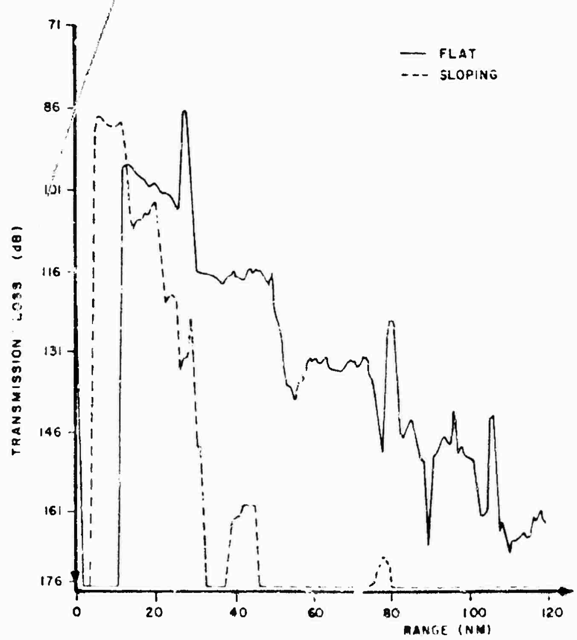


Figure 3. Effect of Sloping Bottom on Transmission Loss.

Of course, some of the bottom-bounce ray energy is transmitted into the bottom and lost, a phenomenon which is also dependent on the effective grazing angle. This bottom loss depends also on the type of material comprising the bottom. The U.S. Naval Oceanographic Office (NAVOCEANO) has categorized nine standard bottom types (one to nine, ranging from rock to light mud). Their effects have been empirically determined; standard bottom loss curves(6) are shown in Figure 4.

Often, the most important range-dependent parameter is the sound speed profile (ssp). Its effect is manifested in ray tracing by a change in the curvature of the rays as they are traced. Figure 2 shows a frontal zone across which the ssp varies from ssp1 on the target side to ssp2 on the sonobuoy side. The effect that such multiple profiles may have on transmission loss is shown in Figure 5 (also generated by GRASS). The changes in the convergence zones (cz's) are notably conspicuous.

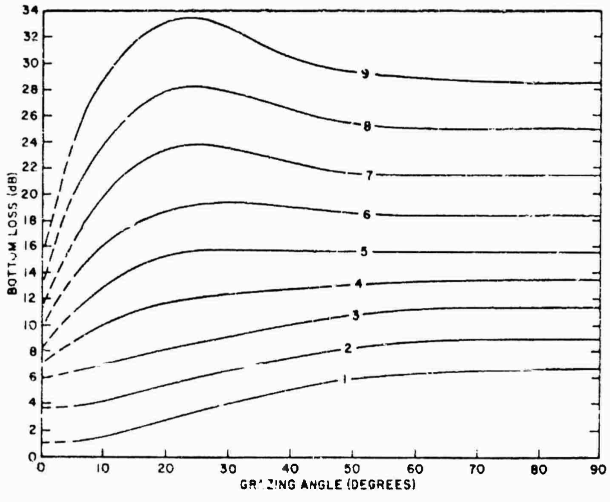


Figure 4. Nominal Bottom Loss Curves for the Frequency Range 1-4 kHz, Divided into the nine NAVOCEANO Classes.

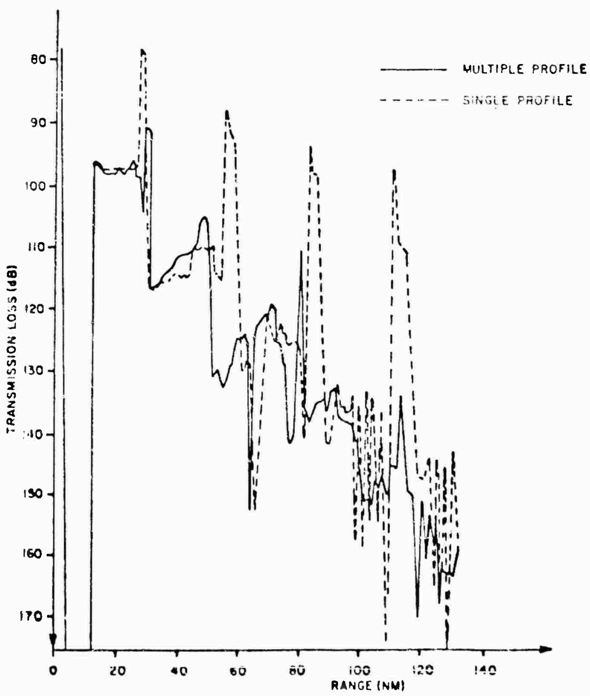


Figure 5. Effect of Range-Dependent Sound Speed Profile (ssp) on Transmission Loss.

The limiting case reached by a steeply sloping bottom is the so-called shallow ocean. Such an area corresponds to an ocean region overlying the continental shelf. In a shallow ocean environment, the surface and bottom interactions of the acoustic energy are so great as to render ray-tracing techniques ineffective, and an entirely different theory must be used, whereby the ocean becomes an acoustic waveguide (see discussion below). An additional complication is the amplified importance of the unconsolidated sediment overlying the bottom. The type of sedimentary material and its thickness both become very influential on the transmission loss curves. Rather than present another loss versus range comparison, Figure 6 shows the effect that different shallow ocean sediment types may have on the beam response of a horizontal array receiver. (The calculations were made using an unshaded, linearly-spaced discrete array with linear steering, using normal-mode theory[7].) Whereas the response pattern for the sand-silt-clay environment is nearly plane wave in character, a change to coarse sand sediment (all other parameters being equal) severely degrades the array response. Beam shifting, broadening, and splitting are all evident. Although our prototype P3-C is not required to model array receivers, the illustration in Figure 6 is useful for surface ship trainer design which must simulate towed arrays.

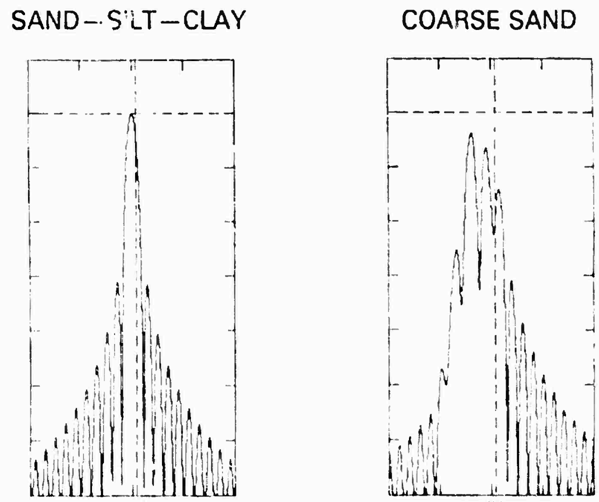


Figure 6. Beam Response vs. Steering Delay Time. A 100-element array was placed at 9 km from the source in a downward refracting ssp. The calculations shown are for (a) sand-silt-clay and (b) coarse sand sediment types. Tick-marks along the y-axis are spaced at 5 dB intervals.

Implementation

In order to include range dependence in the modeled ocean environment, it is clear that the FACT model must be abandoned (or extensively modified). Viable alternatives include many Navy-developed models such as those mentioned above (RAYWAVE II, TRIMAIN, GRASS) and the following: FACTEX (FACT Extended to include range dependence), at Naval Ocean Research and Development Activity (NORDA);* RAYMODE X (or a range-dependent update of it), at Naval Underwater Systems Center (NUSC);[8,9] the FFP (Fast Field Program), at NUSC;[10] the PE (Parabolic Equation) Program, at NORDA and NRL;[11,12] RP-70, at FNOC;* and MOATL

* No documentation currently available.

(Modal Acoustic Transmission Loss), at NRL.[13,14] These models exploit a variety of approaches, thereby emphasizing different aspects of the acoustic transmission problem. The last model cited (MOATL) is especially suited to shallow ocean calculations, and forms the design basis for such calculations in the MPC Ocean Model. These and other existing models may be "mixed and matched" and approximated for a given real-time design effort.

Abandoned along with the direct use of FACT, must be the simplistic table look-up approach. As we have seen, range dependence introduces a host of new variables to be considered for a given ocean gaming area (typically 300 nm to 500 nm square). Along a given transect (target-to-sonobuoy path, as viewed top-side), there may be multiple bottom slopes and bottom types and multiple ssp variations. Because the gaming area is three-dimensional [as opposed to the two-dimensional (r,z only) environment of the research models], changes in lateral (x,y) locations of the sensors produce an almost infinite variety of important range dependencies. (Refer to Figure 2 for definitions of the axes/dimensions.) For example, in Figure 2, if the target is moved perpendicularly away from the plane of the page, then the new transect crosses a wider frontal zone and the bottom slopes are less pronounced. The pinnacle shown (or others) may or may not intersect the transect. It is easy to determine that transmission loss table sizes, for a look-up approach, can exceed 100 million values. Data storage and access time both become problems. Further, implementation of interpolations and corrections to table look-ups is not straightforward. More fundamentally, it is not theoretically clear what these corrections should be. For example, if a particular bottom slope variation along a given transect is changed or moved out in range, then the rays traced may or may not be affected. Whether, and how, are dependent on a number of variables in a way not readily determined without actually tracing the rays.

The straightforward solution to these problems is to calculate the transmission loss on-line, using the actual range-dependent ocean conditions along the transect. (This is the approach of the MPC Ocean Model, as discussed below.) To obtain real-time results, many approximations to the theory must be made. These must be carefully chosen to preserve both the desired effects and their theoretical authenticity.

The final thing abandoned is strict agreement with FACT, or for that matter, with any research model or any set of experimental data. The advantage gained by this sacrifice is the real-time modeling of the important range-dependent effects. With some time and trouble, however, predictability can be regained. The trainer-based model can be exercised in an off-line research-oriented environment to generate loss and even ray-trace plots. These, in turn, can be distilled to a reasonable-size package for use in briefing trainees and by instructors during the training mission.

THE MPC OCEAN MODEL

Design Approach

The MPC Ocean Model has a modular structure which, to allow for modifications and additions, follows the principle of functional decomposition. It consists of both off-line and on-line portions, as shown in Figure 7. Off-line functions include gaming area specification, calculation of gaming area grid tables, and other calculations of data that do not depend on specific transects. These calculations are performed to save time on-line, and result in a database of approximately fifty thousand words per gaming area (about ninety percent of this is for the shallow ocean). The on-line modules calculate the transmission loss at the four passive ASRAP frequencies for up to 51 different target-sonobuoy pairs in about ten seconds. Although the average time per transect is roughly two hundred milliseconds, the actual time for any given transect can vary from several milliseconds to about a second. For this reason, most of the modules execute in background. They are called on demand by the fixed-frame Target-Sonobuoy Scheduler, which tracks the time between updates and assigns priority to each target-sonobuoy pair. The Geometry Model calculates all the non-acoustic parameters along the scheduled transect and then calls the Shallow Ocean or Deep Ocean Model. These two transmission loss models are discussed below.

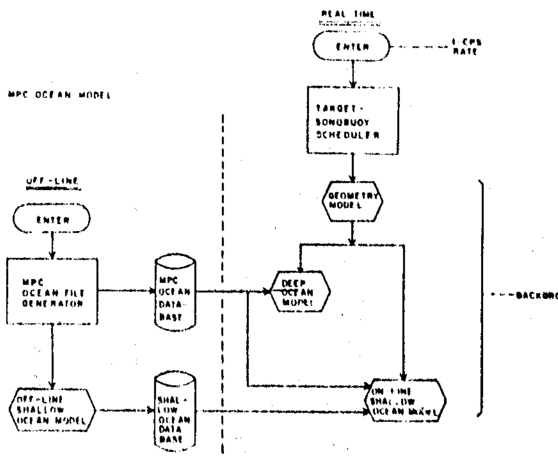


Figure 7. Software Work Breakdown Structure of the MPC Ocean Model.

Even with a whole computer dedicated for the MPC Ocean Model, real-time calculations are not easy to achieve. To this end, all of the on-line modules are written in Assembler language. Furthermore, they employ mostly single-precision (16-bit) words in carefully-scaled fixed-point arithmetic. Double precision is occasionally used when needed, as is the floating-point processor. With computers gaining in speed, use of higher-level languages (e.g., FORTRAN) and all floating-point arithmetic may be possible in similar efforts of the future, but careful deliberation is warranted. The abilities of available compilers to generate efficient machine code must be scrutinized.

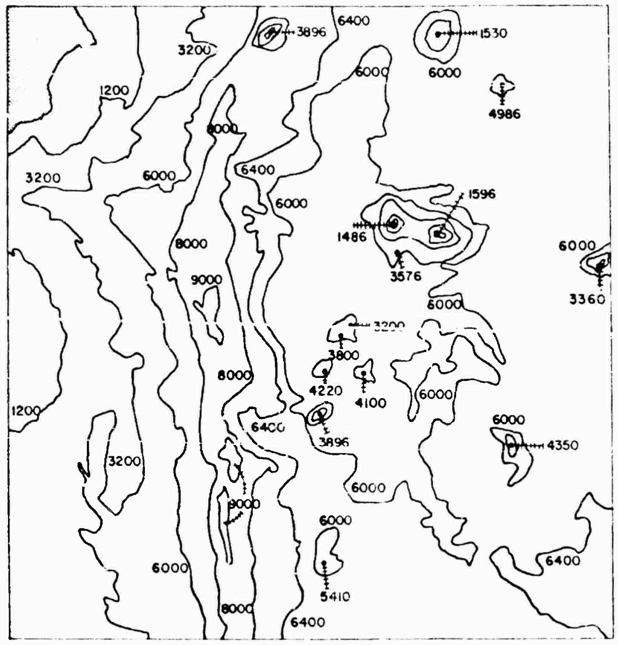
As stated before, approximations to the full theories are also required; some of these are discussed below.

MPC Deep Ocean

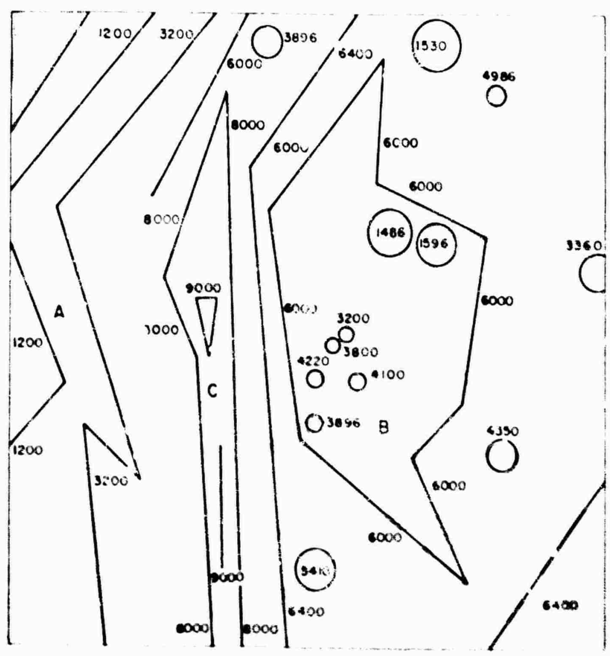
Specification. The MPC Deep Ocean Model calculates the transmission loss at the four ASRAP frequencies when the selected transect is in water deeper than 150 meters. A deep ocean gaming area is shown in Figure 8, where range dependence in water depth is signified by the bottom contour lines. Figure 8a was traced from a bathymetric chart of an area southeast of Japan. Figure 8b illustrates an acceptable specification of this same area for the MPC Ocean Model. The circles represent pinnacles with top-depths as marked. There are many sloping-bottom areas, for example, the one marked "A". An exemplary flat-bottom area is marked "B". A 9000-meter trench is marked "C". Although not illustrated, ridges are modeled similarly.

For the same gaming area as shown in Figure 8, specification of a range-dependent bottom type is shown in Figure 9. The actual bottom variations are given in Figure 9a. Figure 9b illustrates the rectangular-region input method used by the model. The minimum resolution allowed by the MPC Ocean Model is 8 nm. Correspondingly, the off-line module generates a 38x38-value grid table for later access on-line.

In Figure 10, the ocean currents and a front region are shown. Currents are not used directly in the transmission loss calculations. They merely account for the dynamic drift of targets and sonobuoys, and are stored in a grid table similar to that for bottom types. However, associated with currents are temperature fluctuations, which can give rise to a front, across which the ssp shows its greatest variations. As indicated in Figure 10b, the MPC Ocean Model allows for regions of constant ssp separated by frontal zones across which the ssp varies. Some of the front-dependent data are generated off-line to save time. Some are not, however, because the range-variation across a given

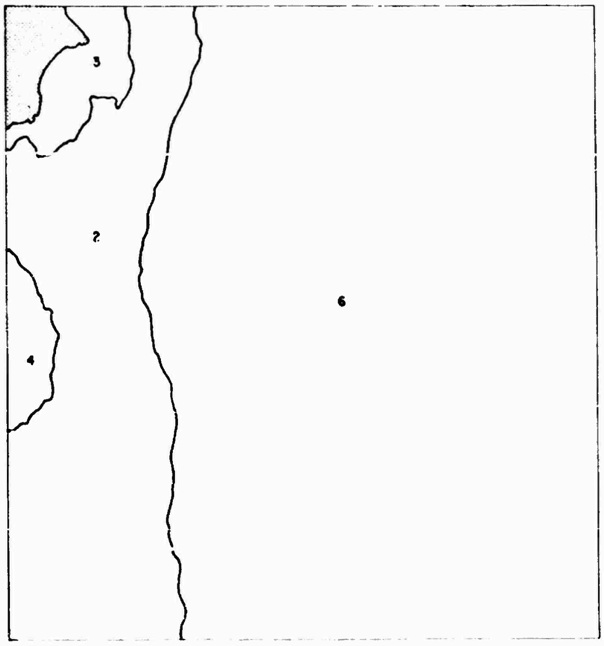


(a)

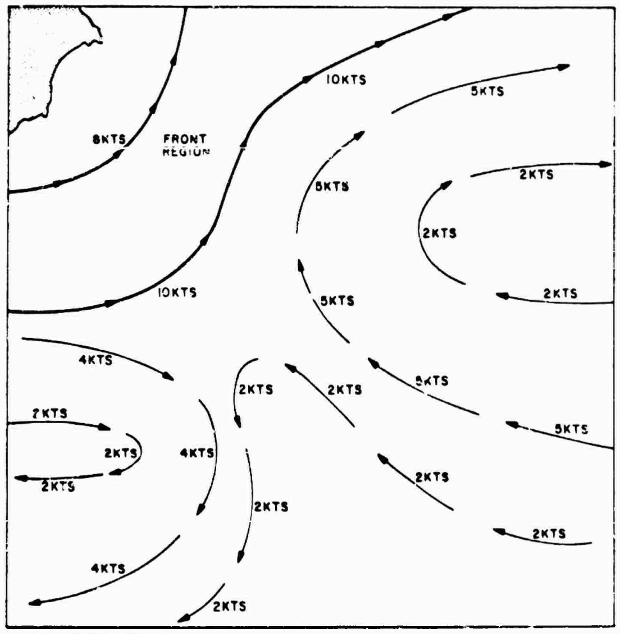


(b)

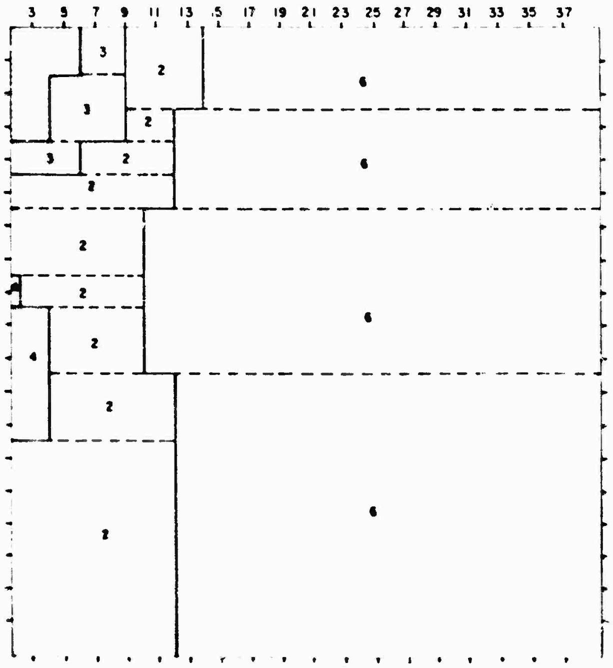
Figure 8. Gaming Area. A 300-nm square area showing bottom contours (depth units are meters). (a) Actual area. (b) Same area as simulated by the MPC Ocean Model.



(a)

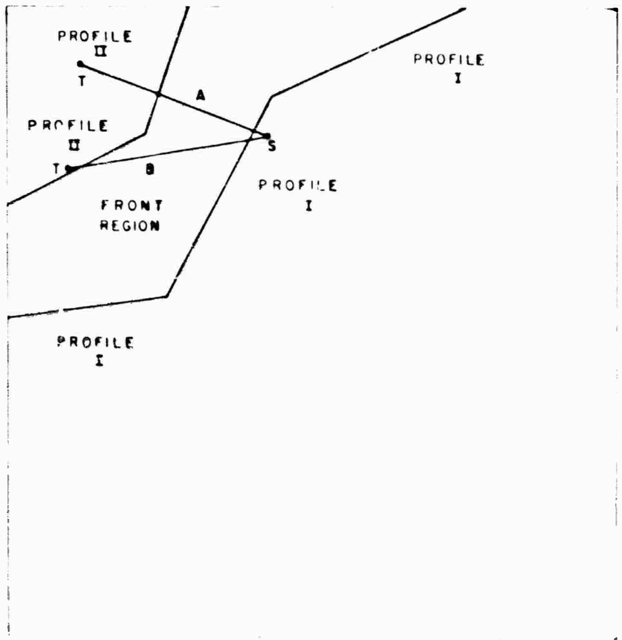


(a)



(b)

Figure 9. Bottom Type. Specification using the NAVOCEANO numbering system. (a) Actual area. (b) Simulated area.



(b)

Figure 10. Front-Region Specification. (a) Actual area, showing currents that help produce the front. (b) Simulated front, demonstrating that the variation from Profile I to II depends on how the front is crossed.

front will change with respect to the bearing of a specific transect (compare "A" to "B" in Figure 10b).

It should be pointed out that the gaming area of Figures 8-10 illustrates the level of range dependence afforded by the MPC Ocean Model, and is not intended for the novice trainee. The simulator-based training period must be organized (and perhaps extended) so as to progress from the simpler to the more complex ocean environments.

Calculations. The deep ocean transmission loss calculations are based primarily on ray-trace theory, which arises as follows:[15,16] theoretically, the transmission of acoustic energy obeys the wave equation, which for a harmonic point source at depth z_0 takes the form:

$$\left[\nabla^2 + \left(\frac{\omega}{c}\right)^2\right]\Phi = -\delta(x)\delta(y)\delta(z-z_0). \quad (1)$$

Here, $\omega = 2\pi f$ is the angular frequency. The sound speed c and the velocity potential $\Psi = \Phi e^{-i\omega t}$ are both functions of position. The acoustic pressure, hence the transmission loss, can be calculated from the velocity potential. Assuming a solution in the form

$$\Phi = Ae^{iW} \quad \text{(A,W functions of position)} \quad (2)$$

results in the eikonal equation,

$$\left(\frac{\partial W}{\partial x}\right)^2 + \left(\frac{\partial W}{\partial y}\right)^2 + \left(\frac{\partial W}{\partial z}\right)^2 = \left(\frac{\omega}{c}\right)^2 , \quad (3)$$

which is the basis for ray tracing. The surfaces of constant phase (W = constant) are the wave fronts, and the normals to these are acoustic rays.

The calculational procedure is to trace the various rays from the source out to the receiver range, assign the rays to families (having like trace histories), and then perform standard ray-intensity spreading techniques to get the transmission loss. To accomplish this in real-time, the MPC Ocean Model makes a fundamental approximation. Only 20 rays are traced, as opposed to hundreds or even a thousand as are traced by most research models. To enhance the value of these 20 rays, there is extensive logic to direct the ray fan up or down, and to adjust the angular spacing between the individual rays leaving the source.

Equation (3) shows the dependence of ray tracing on variations in sound speed. Consider first a constant ssp (non-front) region, such as that where the target is located in Figure 11. As shown there, the MPC Ocean Model assumes a piece-wise linear ssp, with up to five layers, in each of which the sound speed gradient is constant. This is an assumption also made by many research models, with the convenient result that the ray path in each layer follows the arc of a circle. This is an aid to real-time calculations, whereby several trigonometric table look-ups (along with a few other calculations and extensive logic) suffice to trace a given ray through a given layer. For some rays, such as the one labeled "A" in Figure 11, symmetry allows the stored data for several layers to be quickly "folded out" in range (without recalculation). At the onset of the front, however, new calculations must be made. After studying several research models (including GRASS and TRIMAIN), the front-region techniques of RAYWAVE II were adapted for use in the MPC Ocean Model.[3] As shown in Figure 11, the front is broken into triangular regions. For each triangle, an average sound speed gradient is determined, which now has a range-component as well as a depth-component. By a rotation of coordinates, however, the range dependence is temporarily "eliminated"; the ray is efficiently traced to the next boundary in the standard manner, and then an inverse coordinate rotation is performed. Although quick, it is found that the front-trace calculations consume the major portion of the total transect calculation time. This is the price paid for range dependence.

To model a sloping bottom, the range and grazing angle of the ray at the point of bottom interception must be determined (refer to Figure 2). This requires finding a solution for the intersection of two equations, one being the arc of a circle (the ray), and the other a sloping line (the bottom). To save time during most of the "normal" trace, these considerations (i.e., calculations for determination of a bottom intercept) are not made until a ray has penetrated the so-called "false bottom," a pre-calculated parameter which is illustrated in Figure 11 (ray penetration occurs at point "B").

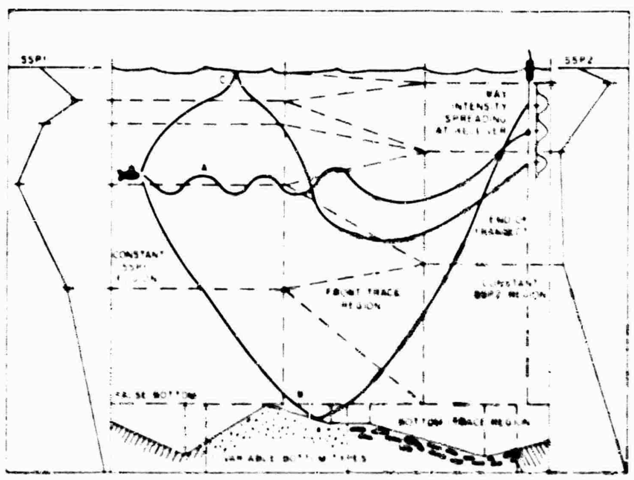


Figure 11. Boundaries Between Ray-Trace Regions.

Having extended, extolled, and exhausted ray-tracing techniques, it must be conceded that there are special cases where the theory breaks down. In going from Equation (1) to Equation (3), one basic assumption must be made. The fractional change in the sound speed gradient over the distance of an acoustical wavelength must be small in comparison with the gradient. In terms of frequency, this means that:

$$\frac{\partial^2 c}{\partial z^2} << 2\pi f. \quad (4)$$

Thus, at the bottom of the ocean, the ssp discontinuities are such as to render Equation (3), hence ray tracing, invalid. In the deep ocean, however, where there are few bottom encounters per ray, bottom loss may be assigned in an empirical manner (the curves were given in Figure 4) and the results are acceptable. In a similar way, sea state-dependent and frequency-dependent surface loss may be assigned to rays reflecting off of the sea's surface[6] (see ray "C" in Figure 11). In a shallow ocean environment, the extensive surface and bottom interactions require a different approach altogether (see below).

More generally (other than at the bottom or at the surface), wherever the sound speed gradient changes abruptly, such as at the layer boundaries in the MPC Ocean Model, there is a chance that ray tracing will break down. These commonly encountered special cases include the phenomena of leakage into a shadow zone, intensity "roll-off" from a cz, and a surface duct. They are illustrated in Figure 12, where a plot of relative loss has been included to show their effects on transmission loss. Reference to Equation (4) shows that the deviation of these effects from ray-trace predictions are more pronounced at lower frequencies.

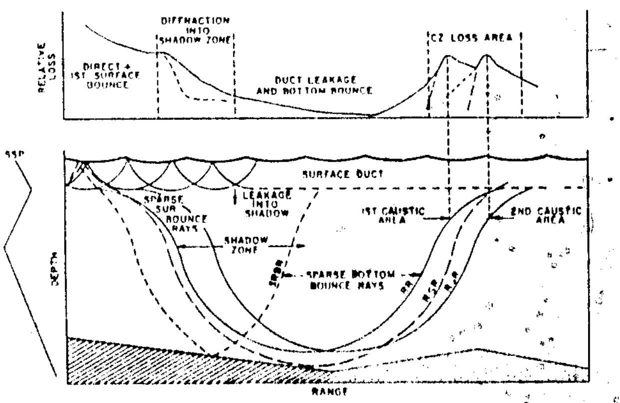


Figure 12. Deep Ocean Special Cases.

The MPC Ocean Model adapts the findings of research workers[17] regarding the frequency-dependent and ssp gradient-dependent effects of a shadow zone. In this adaptation, the "limiting rays" used to define the shadow zone are traced, so that range dependence enters as it does for the rays in the standard fan.

The other special cases are treated by the FACT model in an empirical, frequency-dependent manner. The asymptotic intensity method for roll-off from a cz caustic (from FACT) is modified and limited to give the basic effects in a real-time framework. However, the actual cz determination is an integral part of the MPC ray-trace procedure, and as such, models the range dependence not considered by FACT. MPC Ocean surface duct calculations also follow those of FACT. They are dependent, however, on such factors as the sound speed gradient and the duct depth, both of which are allowed to vary across a front in the MPC Ocean Model. Range dependence is included through these parameters.

Pinnacles also represent a special case. Diffraction around a pinnacle has been determined to be a negligible effect for frequencies above 25 Hz,[18,19] so that modified ray tracing can be retained. As shadowing can be important, this effect is modeled simply by cutting off any rays that intersect the pinnacle (refer to Figure 2).

MPC Shallow Ocean

Introduction. The MPC Shallow Ocean Model has the task of calculating the passive transmission loss when the transect is in water shallower than 150 meters. In such an environment, ray-trace theory is better replaced by the more exact normal-mode theory, as has been mentioned. This is effected by dropping the assumption, Equation (4), which led to the eikonal equation, and returning to solve the wave equation, Equation (1), directly. To tailor normal-mode theory to fit a real-time framework, the MPC Ocean Model makes use of the adiabatic approximation, that is, the range dependence is slow enough that the wave equation is "locally separable," and further, that the modal solutions so obtained involve no inter-coupling of energy. These approximations are used by almost every research model, and have been shown[20] to be quite good, even for bottom slopes of up to 10 degrees. Implementation in the MPC Ocean Model involves the off-line solution of a range-independent problem at several user-specified environmental sites. During trainer operation, the on-line module performs a certain range-average of the prestored modal parameters of those environments which are crossed by the transect.

Off-Line Module. By assuming idealized boundary conditions, the velocity potential in Equation (1) is given by a certain sum of normal modes, or eigenfunctions $u_n(z)$; each satisfies the depth-separated wave equation:

$$\frac{d^2u_n}{dz^2} + \left[\left(\frac{\omega}{c}\right)^2 - k_n^2\right] u_n = 0 , \qquad (5)$$

where k_n is the eigenvalue or modal wave number.[15,16] This method is adapted for use by the MPC Shallow Ocean Model, following the Navy research model MOATL.[13,14] For a fixed eigenvalue, depth-variations in the sound speed may cause the quantity [in brackets in Equation (5)] to vary from positive to negative, in which case, the character of the modal solution u_n will vary from sinusoidal to exponential. Sample ssp's and corresponding normal modes, which represent depth distributions of the acoustic pressure, are shown in Figure 13. It is evident there, that such features as surface ducts and shadow zones are intrinsically modeled by the normal-mode approach. Cz's are also implicit, although their occurence in the waveguide-like shallow ocean is rare.

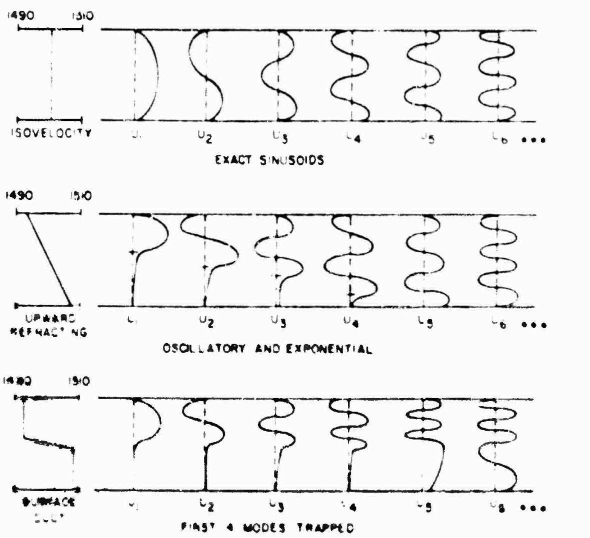
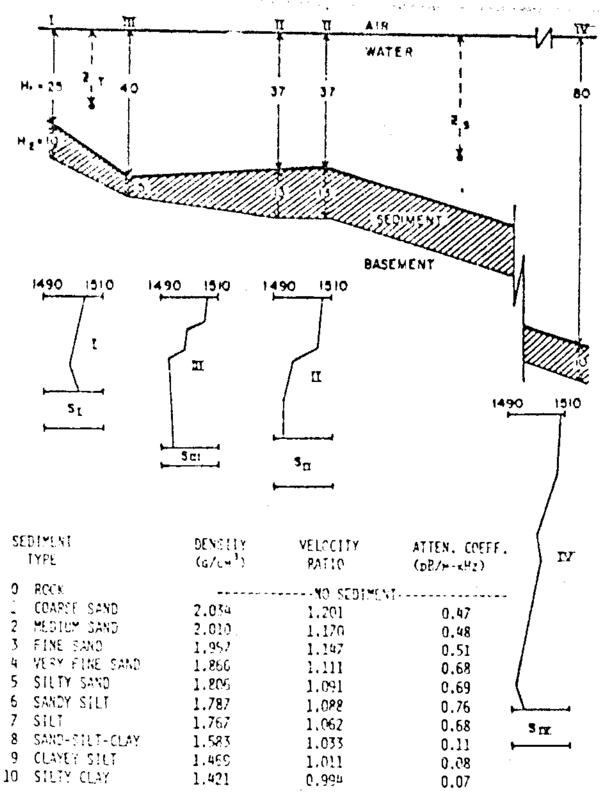


Figure 13. Normal-Mode Pressure Distributions (sound speed units are m/sec).

Equation (5) is solved off-line for each shallow ocean environment, each of which is independently defined by its water depth, ssp, and sediment type and thickness. A shallow ocean gaming area in the East China Sea is shown in Figure 14. The actual area (Figure 14a) is modeled (Figure 14b) using six independent environmental contours, labeled with Roman numerals. For the first four of these (corresponding to the transect shown in Figure 14b), a hypothetical model input is illustrated in Figure 15. The sediment type names given are standard in the literature, as are their properties,[13] which are supplied internally by the off-line module. Effects of sediment variation have already been demonstrated in Figure 6.

Figure 14. A Typical Shallow Ocean Gaming Area. (a) Actual area. (b) Simulated area. (Depth units are meters.)



SEDIMENT TYPE	DENSITY (g/cm^3)	VELOCITY RATIO	ATTEN. COEFF. (dB/m-kHz)
0 ROCK	---------------NO SEDIMENT---------------		
1 COARSE SAND	2.034	1.201	0.47
2 MEDIUM SAND	2.010	1.170	0.48
3 FINE SAND	1.957	1.147	0.51
4 VERY FINE SAND	1.866	1.111	0.68
5 SILTY SAND	1.806	1.091	0.69
6 SANDY SILT	1.787	1.088	0.76
7 SILT	1.767	1.062	0.68
8 SAND-SILT-CLAY	1.583	1.033	0.11
9 CLAYEY SILT	1.469	1.011	0.08
10 SILTY CLAY	1.421	0.994	0.07

Figure 15. Environmental Parameters Along the Transect Defined in Figure 14b

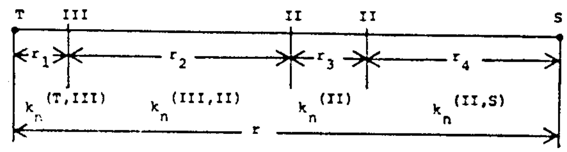
For up to six environments, Equation (5) is solved separately for each of the four ASRAP frequencies (thus, frequency-dependent effects are inherent). For each of these 24 cases, a maximum of 25 normal modes are calculated. Each stored eigenfield consists of 76 depth values of the eigenfunction (normal mode), the eigenvalue, and two attenuation coefficients. The total storage for a given gaming area is approximately forty-five thousand (16-bit) words. The 25-mode limit is a fundamental approximation of the MPC Ocean Model, made to save storage and on-line mode-summation time. Although the actual number of modes supported by the deepest environments for the highest frequency can exceed 400, truncation to the lowest-order 25 is justified for training purposes because all the salient features are retained.*

On-Line Module. When the wave equation is solved directly via normal-mode theory, it is found that the transmission loss is given, under the adiabatic approximation, by:

$$TL = -10\log_{10}\left\{\frac{2\pi}{H_T H_S}\cdot \sum_{n=1}^{N}\left[\frac{u_n^{(T)}(z_T)\cdot u_n^{(S)}(z_S)}{\beta_n^{1/2}}\; e^{-\Delta_n}\right]^2\right\}. \qquad (6)$$

* Verified by private calculations, and also by Reference (21).

The included range dependence is illustrated by explaining the terms in Equation (6). The terms H_T and H_S are the water depths at the target and sonobuoy locations. The use of their product is an extension of H^2, found in the flat-bottom case. In the summation of modes, $u_n^{(T)}$ and $u_n^{(S)}$ are similar range-dependence extensions, representing the two different sets of modes generated for the target and sonobuoy locations. As it is unlikely that the target (sonobuoy) will be located directly on one of the input environmental contours, the MPC Shallow Ocean Model performs an interpolation between the pre-calculated sets of modes at the two environments closest to the target (sonobuoy). The depth of the target is z_T; $u_n^{(T)}(z_T)$ is thus, the closest of the 76 stored depth values to this depth (and similarly for the sonobuoy modes). The term β_n is the transect-averaged value of the product of the eigenvalue and the total range, $k_n r$. Schematically, for the specific transect shown in Figures 14b and 15, there is:



$$\beta_n = k_n^{(T,III)} r_1 + k_n^{(III,II)} r_2 + k_n^{(II)} r_3 + k_n^{(II,S)} r_4,$$

where $k_n^{(i,j)}$ = n^{th} modal wave number averaged between environments i and j.

The term Δ_n is a similarly transect-averaged value of $\delta_n r$, where δ_n is the modal attenuation factor and includes water absorption, sediment and basement attenuation, and sea surface scatter. These depend on the sediment type, sea state, etc., and enter the theory via perturbation methods.

The total number of modes in the sum is N, which is dependent primarily on frequency and water depth. The shallowest water depth found along the transect is employed to limit N. In this way, sloping bottoms are modeled. They are also modeled implicitly through the solutions u_n, k_n, δ_n at the various input environments. Range dependence in the ssp (or a front) is similarly modeled implicitly.

Pinnacles are modeled by using their top-depths to apply mode cut-off (i.e., to further truncate the value of N). For pinnacles reaching close to the sea surface, the lower frequencies may be completely cut off. For the island in Figure 14a (modeled by three overlapping pinnacles of zero top-depth in Figure 14b), all frequencies are cut off.

The implementation of adiabatic mode theory is a quick and effective way of incorporating range-dependent shallow ocean environments into a trainer-based transmission loss model. Most of the real work [i.e., solution of Equation (5)] may be performed off-line. In the case of the MPC Ocean Model, off-line shallow ocean calculations consume about ten minutes per gaming area. To calculate Equation (6) on-line, takes an average of 40 milliseconds per transect.

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THE INTEGRATION OF MODELS USED FOR TRAINING EQUIPMENT REQUIREMENTS DERIVATION: THE INSTRUCTIONAL SYSTEMS DEVELOPMENT, RESEARCH DESIGN, AND SYSTEMS ENGINEERING PROCESSES

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ABSTRACT

Presently, no set of algorithms has been developed which assesses all variables involved in deriving training device requirements. While the Instructional Systems Development (ISD) process provides useful information for deriving requirements for those aspects of the trainer which are specific to aircraft configuration, it provides insufficient information for deriving "best method" of simulation and instructional feature requirements. The Systems Engineering Process, on the other hand, is a generic guide and does not consider training variables. If these processes are used concurrently, two separate data bases — one training-related, one engineering-related — will evolve without any seeming correlation. By adding research design, the effect of the training device design upon training effectiveness can be assessed. By collecting the needed data based upon individual feature characteristics, rather than implementing a single process or set of algorithms to derive all feature requirements, the training equipment contractor can develop equipment maximizing training and cost-effectiveness.

INTRODUCTION

Military instructional systems, including simulation devices, have become very important due to the rising costs of training personnel on the actual equipment. There is a trend for more realistic simulations of aircraft, including associated airborne and weapons delivery systems. This trend has caused a corresponding upward spiral in both the initial procurement and subsequent life cycle costs associated with training of military personnel. Pohlmann, Isley and Caro[1] noted that while expense and fidelity of newer training equipment have increased, efficient design concerning instructional features has decreased, having a negative impact on the training value of the equipment. They state, "Because of the cost of high fidelity devices, the development of simulator (and other training equipment) designs that permit more efficient training is a necessary goal."

The military customer began to closely analyze training objectives, population variables and other factors which drive the effectiveness of equipment design. The Air Force uses the Instructional Systems Development (ISD) process for that purpose. Air Force Regulation 50-8[10] defines ISD as a systematic but flexible process used for planning, developing and managing education and training programs. More specifically, ISD sets guidelines to aid training managers in identifying training requirements, translating the requirements into valid learning objectives, selecting proper training strategies, developing effective training delivery systems and providing quality control. Unfortunately, ISD is used before the training equipment is developed and thus does not analyze the impact of instructional feature design on the training program. The contractor usually acquires the task of investigating the effects of new designs or modifications on the learning situation and user system interactions, as well as collecting any missing front-end data. Traditional system engineering processes, or the sets of algorithms used for transforming an operational need into a description of system performance parameters and a preferred system configuration,[1] were not originated for use in training situations and do not provide means for collecting and analyzing that type of data. Those trainer requirements affected by training variables, then, which were left for the contractor to derive, are often based on software/hardware compatibility and other engineering considerations. This results in customer-contractor misunderstanding, loss of time, increased costs, and often a training product which does not fulfill training requirements.

The training literature contains numerous examples of these situations. Semple, Cotton and Sullivan[1] performed an extensive review and critique of instructional features for the Air Force in which they stated:

An issue of continuing concern is that the aircrew instructor's Aircrew Training Device (ATD) job seems to have escaped needed detailed analysis. The issue is an Instructional System Development (ISD) approach to ATD instructor training. The same issue is of concern with respect to console design, because consoles are pieces of equipment meant to support men in the doing of their jobs. It is only reasonable, therefore, to start with a thorough knowledge of the tasks and performance the instructor's job requires so that consoles can be designed to support these requirements. It probably is the case that at least some ATD manufacturers take the instructor's tasks, sequences, workloading and coordination requirements into account when they design ATD instructor consoles. What is needed, however, are improved guidelines for relating instructor task requirements to console design characteristics so that what results will be more predictably workable.

Guidelines are needed for incorporating both instructor and trainees task variables into the systems engineering approach. The means to do this already exist, but as Bertalanffy[1] states in <u>General Systems Theory</u>, "Modern science is characterized by <u>its ever-increasing specialization</u>, necessitated by the enormous amount of data, the complexity of techniques and theoretical structures within every field ... in consequence, the physicist, the biologist, the psychologist and the social scientist are ... encapsulated in their private universes, and it is difficult to get word from one cocoon to the other." This paper will attempt to integrate existing approaches from education (training), psychology (experimental and learning theory) and systems engineering into a singular working system designed to derive training equipment requirements. To be more specific, the three systems referred to are:

1. The Instructional Systems Development (ISD) process and other "front-end" analyses performed by the customer.

2. The scientific method, including experimental designs and hypotheses revolving around learning theory.

3. The standard systems engineering process as defined in MIL-STD-499A, Appendix A.

The decision to combine these approaches was not artificially or arbitrarily imposed. Training equipment engineers have used these systems in an unstructured form before. Clarification of the interactions between the systems is needed, however.

As a side note, these processes have two common characteristics. First of all, they are systems designed to derive data on which to base decisions. The nature of the information derived from these systems, however, is quite different. The training device contractor must assess each specific feature as to the type of information needed to produce an efficient and effective design for that specific component of the training device. The contractor will need a different set of information, for example, to derive performance measurement system requirements, which is more training related, than to derive crew station design for a Weapons Systems Trainer (WST), which is more dependent upon the aircraft configuration. Montemerlo[14] assessed that there are no theoretical or empirical bases for a single set of algorithms which can be used to develop all programs of instruction

Similarly, we found that, because the varying degree to which the contractor will employ each of the different processes varies for each training equipment feature, it is impossible to provide a single set of algorithms which can be used to derive all training equipment requirements.

Secondly, at some point in all three processes the human must make some subjective inputs. In ISD, there is a relatively objective method of collecting data (task analysis) but it is still the task of the training experts to use that data to determine objectives, arrange a syllabus and choose appropriate media[16]. Likewise, the researcher develops hypotheses, determines criteria and the experimental design, and the engineer determines the method of simulating and sets the point at which the cost of that method outweighs the benefit. Computer-aided systems have been developed to organize data[18], but the human must still interpret this data. The results of training equipment requirements derivation process, therefore, are only as good as the human resources involved in the loop.

Examples given in the following sections deal primarily with the Air Force as the customer in the procurement of an advanced WST. This system approach, however, can be modified for any customer and can apply to the entire family of training devices, including general training equipment, maintenance bench trainers, integrated systems maintenance trainers, part task trainers (PTTs), mission trainers (MTs), operational flight trainers (OFTs) and weapon system trainers.

BACKGROUND

ISD is used at several levels in the Air Force hierarchy to make specific decisions. Ideally, the process begins with an analysis of system requirements considering all constraints. For example, in the Department of Defense (DOD), an analysis occurs to determine the need for a new long-range combat aircraft. At the same time, DOD or AF Hq must analyze and define the mission it is to perform. At some other level, an analysis may occur to examine the subsystems, support systems, training equipment (including simulators), personnel needs and myriad other considerations. At some point, the user of the proposed simulator is brought into the ISD process. This group will apply the first step of the ISD process by performing an in-depth task analysis and target population study. The result of this effort will be a definition of all knowledges and skills to be trained, that is, education and training requirements. The education and training requirements must then be written as objectives. These objectives must state a specific performance, the conditions under which the performance takes place and a standard for the performance[17,9,8].

The results of this front-end analysis are input to the design criteria data base from which the training device contractor designer applies the systems engineering process to derive training equipment requirements (see Figure 1). The data base also includes all data describing actual equipment (usually aircraft, in our case) configuration, performance, stability, on-board systems, etc., as well as data describing friendly and hostile environments. This kind of data usually takes the form of technical reports, tecnical orders (T.O.s), engineering drawings, and memoranda of telephone conversations and meetings. Ideally, the results of the ISD process should be supplied in raw form including training objectives, performance, conditions and standards of performance, and all available task analysis information. Realistically, the results are usually "refined" into training equipment requirements given to the contractor, usually in the form of a Prime Item Development Specification (PIDS). To illustrate where ISD is currently being employed by the Air Force, the process flow for training equipment is illustrated in Figure 2.

PROBLEM

The contractor can use the data base derived from the ISD process to identify the essential training media elements of the training equipment. Training media features operationally defined are representations of the actual equipment configuration, performance characteristics, etc., which are needed for transfer of training. They provide stimuli similar to those provided by the actual equipment through use of actual equipment components (crew station control panels), simulation (motion base) or abstract representation (checklists for emergency procedures given on a Computer-Aided

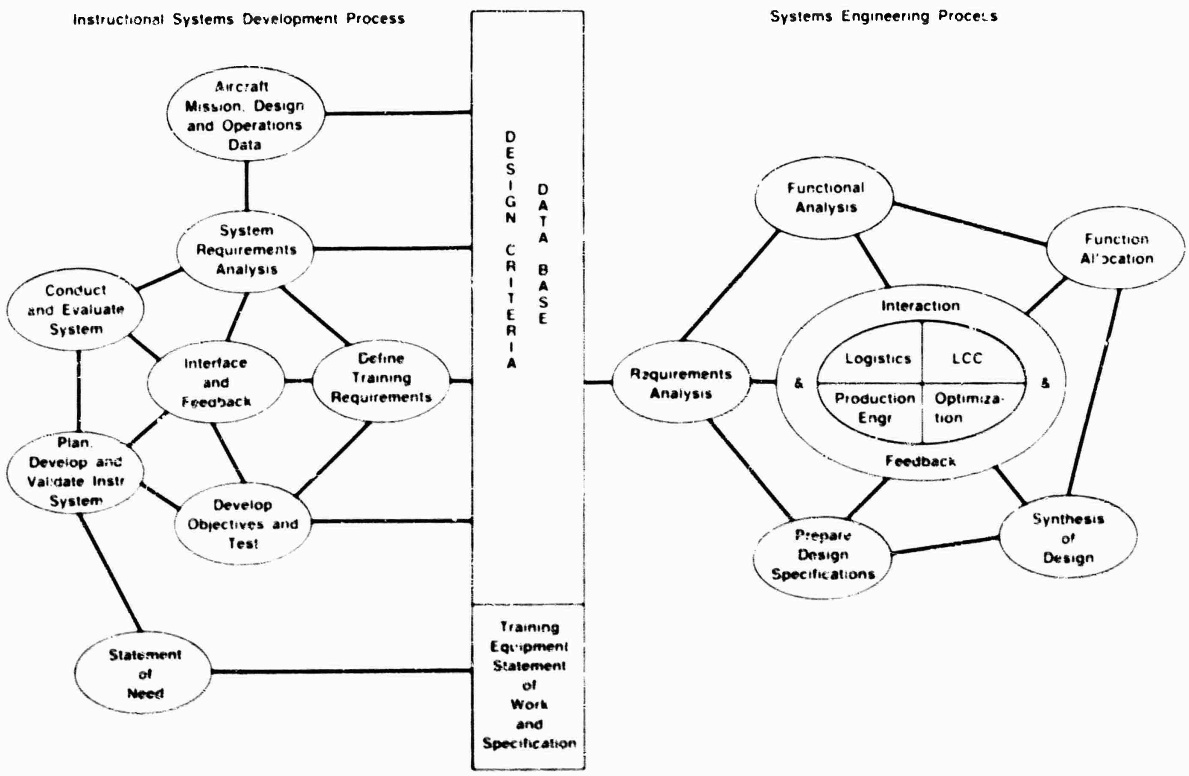
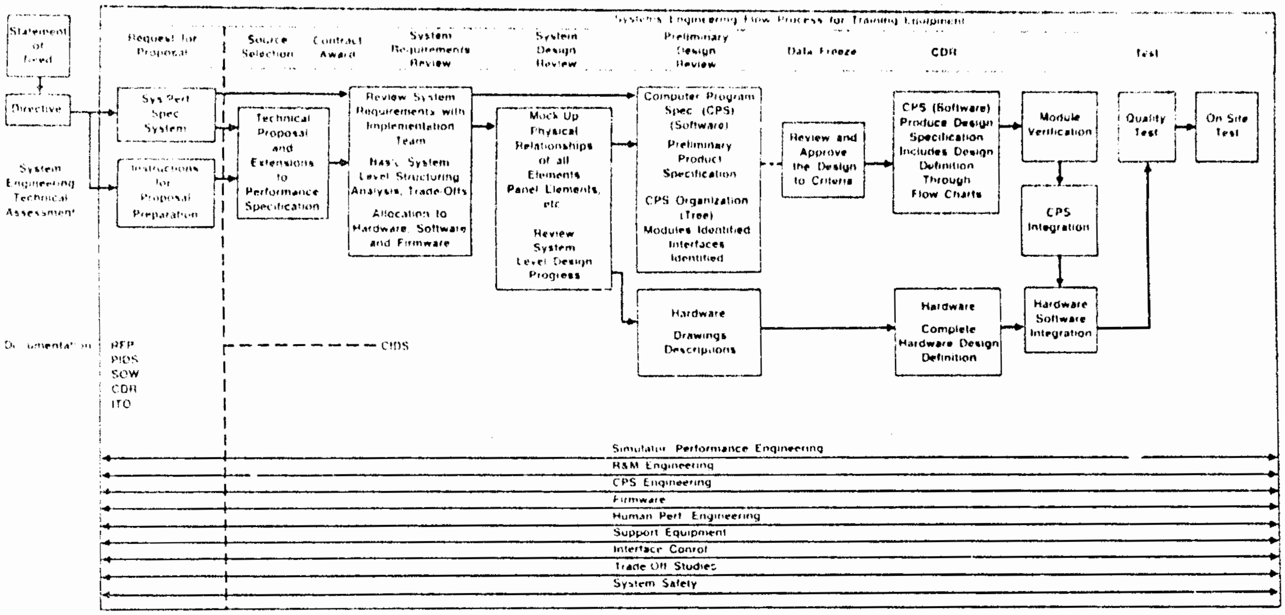


Figure 1. Relationship of ISD and Systems Engineering Processes



RFP - Request for Proposal
PIDS - Prime Item Development Specification
SOW - Statement of Work
CDR - Critical Design Review
ITO - Instructions to Offerers
CIDS - Critical Item Development Specification

Figure 2. Application of Instru tional Systems Development to Total System (per Doty, 1980)

Instruction (CAI) system). While ISD can be used to answer "what" is needed for training, no methods are provided for determining "how" to represent what is needed. For example, eye movement (assessed in the human factors stage of ISD) can be translated into visual simulation (out-the-window) requirements for brightness, scene contrast and system resolution. The method for providing visual effects is usually determined in the systems engineering process which addresses variables such as hardware/software compatibility, costs, materials, etc. A method for assessing the effectiveness of the design in meeting training requirements is not included, however, in the systems engineering process or the ISD process.

Doty[4] suggests that the methods for determining design effectiveness do exist in the ISD process, that the real problem is that ISD is used only as a front-end analysis and not throughout the development of a simulation system. Recent studies within the Air Force, however, have indicated that, in practice, the ISD process as it currently exists provides little systematic guidance for the selection of specific objectives. Numerous "considerations" are suggested, but little formal structure is available to make trade-offs among all of the considerations. The PIDS often states simulation requirements for the training media elements, but it is questionable as to whether the decision was based upon assessment of design effectiveness or other factors. In cases where no "best method for simulation" has been defined, the contractor will need to implement research design to complete the data base and perform formalized analyses aimed at maximizing cost-effectiveness and training effectiveness.

Regardless of the amount of research employed by the contractor, the ISD and front-end analyses data base is always the starting point for developing the design of training media elements. The front-end analysis, however, provides practically no information for determining design of those elements which are more independent of the aircraft configuration, or instructional features. The variables involved in instructional features design are more dependent upon learning theory and perception. Specifically, instructional features include systems such as automatic briefing/debriefing, automatic demonstration, automatic monitoring, automatic performance measurement, automatic record/replay, freeze, mission file build, etc.; on a broader scope instructional features can include anything from environmental control to instructor station configuration.

RESEARCH DESIGN IN SYSTEMS ENGINEERING

Figure 3 illustrates a top-level flow chart for implementing research design in training equipment design. As mentioned previously, more detailed approaches can only be arrived at by assessing variables concerning the individual feature. Some considerations for developing the detailed approaches include:

1. The classification of the feature -- Is the feature a training media element or an instructional element of the trainer? If it is a training media element, the contractor can obtain a great deal of valuable knowledge for design from the training objectives and requirements, as well as any task analyses data. If the ISD data is incomplete or unavailable, the contractor may need to perform any front-end analysis necessary to complete the data base.

   If the feature is an instructional element, several methods are available for performing front-end analyses. Pohlmann, Isley, and Caro prescribe a method of creating design guides for instructional features. The method includes identifying the feature, defining the feature, its purposes and intended use, function description, concurrent events and diagrams. It is suggested that supporting analysis (review of previous studies) be added to this format[7] to account for previous research into the instructional feature. The purpose of this step is for the contractor to attain a full understanding of the feature's intended use in meeting training requirements and to narrow down design options. If there is sufficient information in the data base, if the design requirements have been defined explicitly in the PIDS, or if an existing system satisfies the training requirements without any problems, then the contractor may end the process with this step.

2. Review of existing systems -- If questions still exist after reviewing the front-end analyses, then the contractor may need to critique existing systems for any problems in meeting training and user requirements. Depending upon the nature of the feature, the contractor may need to perform a needs assessment on the training population and/or

instructor population, ask for clarification from the customer, or review applicable theories of perception and learning.

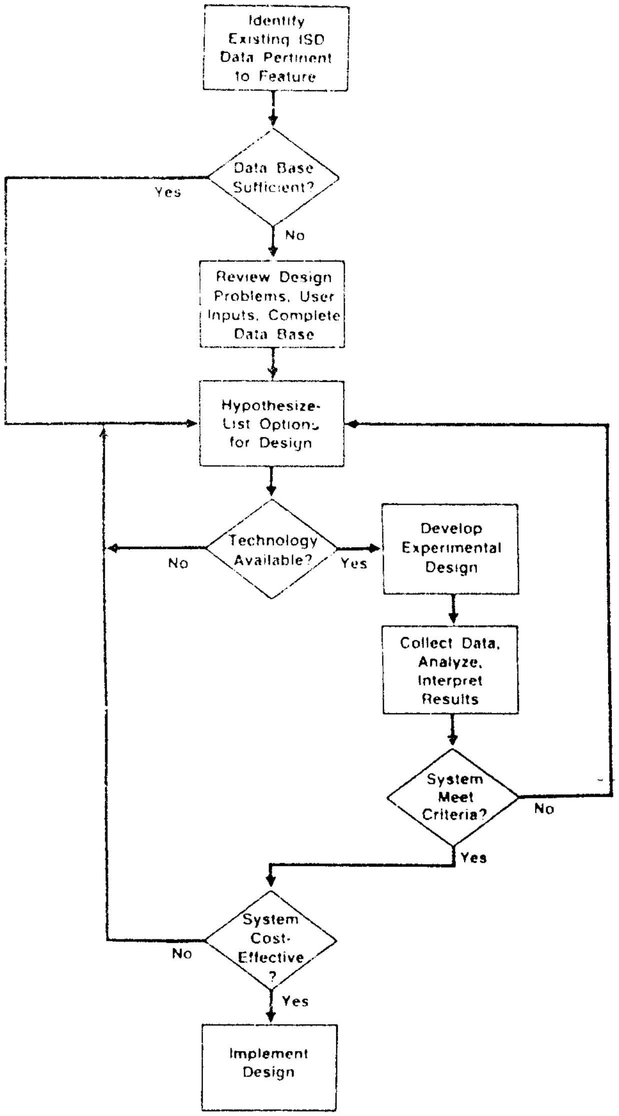


Figure 3. Top Level Description of Training Equipment Design Method

3. Hypothesis — Options lists for design. There will undoubtedly be some disagreement as to whether this step should come before or after a review of available technology. By reviewing technology first, the designer is often influenced by its limitations. It is suggested, therefore, that the designer become as creative as possible in developing solutions to meet the requirements, and then search for the technology which comes as close as possible to conforming to the solution, rather than the design conforming to the technology.

4. Experimental design development — The contractor has the most flexibility at this stage in setting the criteria for success. The criteria must be relevant to the goal, and the designers should ask themselves: How can a decision system be tested as to its goal fulfillment and efficiency? Does the system fulfill its purpose at a responsible degree? Does it satisfy the minimal criteria set for it? Shall it be accepted, revised or rejected? There exists marked differences between the testing of cognitive hypothesis and theories and the testing of instrumental hypothesis and systems, as illustrated in Figure 4. The designers must be aware that they are setting the criteria for one system tailored for one set of training requirements and not trying to create a set of "truths" to meet all trainer requirements

Cognitive Hypotheses (Dominates in Pure Science)	Instrumental Hypotheses (Dominates in Applied Science)
Structure of the general form: "All A are B" and variations	Structure of the general form: "To attain A, do B" and variations
Non-teleologic	Goal oriented
Efficiency irresponsive	Highly efficiency responsive
Rigorous criteria of acceptance based on truth assumption	Relaxed criteria of acceptance based on assumption of better goal attainment
High degree of generality	Limited degree of generality
Not behaviorally limited	Predominantly oriented toward decision behavior
Oriented toward cause and effect relations	Oriented also toward reason and action relations

Figure 4. Some Characteristics Distinguishing Cognitive from Instrumental Hypotheses

The method of testing must also be relevant for answering unresolved requirements. For so long the training community has felt that task analysis was the tool. It is suggested for use in determining function allocation in the systems engineering process and for determining training requirements during the ISD process. That method usually works only for the training media elements of the trainer where the aircraft configuration is well defined. For instructional feature design assessment, task analysis may become too cumbersome or, even worse, counterproductive. Folley[6] stated that the variety of tasks, and the complexity of human behavior, would not permit the reduction of task analysis to a simple routine method. It may be better, for instructional feature design, to assess instructor acceptance, operation time, training time and overall training effectiveness and efficiency.

5. Cost-effectiveness — After the results of the research have been identified, the systems engineering process can be used to determine cost-effectiveness, technology availability, etc.

There are several words of warning about using this system of which the designer should be aware. This method falls into the realm of applied science. Mattessich[12] differentiates between pure and applied science:

"Both pure and applied sciences fulfill a cognitive as well as an instrumental task, but in each branch these two ingredients are mixed in different proportions. Roughly speaking, one might say that the cognitive element dominates pure science: All of its statements have a sufficiently high degree of reliability to be assumed true, but their specific usefulness may not be established. Whereas the instrumental element dominates applied science: All of its statements are assumed to be useful but their degree of reliability is not necessarily high enough to regard them as true in the conventional sense. Thus, the applied sciences use the same methods as the pure ones (observation and measurement, induction and deduction, interpretation and testing, etc.) but with a fairly specific purpose in mind, and under consideration of an economic or cost-benefit criterion. The distinction between pure and applied science is not simply that between 'knowing' and 'doing,' but rather that between believing for the sake of knowing' and 'believing for the sake of doing.'"

The economic element, assessed through the systems engineering process will, of course, influence the selection of the final feature design. It is important, however, that designs which proved to be effective but not used are documented, as technologies may later develop which will make those designs feasible.

Certain "pure" sciences are taken into consideration in this "applied" science approach. The contractor may need to take responsibility for collecting the pure research data, too, rather than relying upon "known" theory, particularly when dealing with instructional features. As McKeachie[13] states, "The past two years have been bad ones for those of us who have attempted to apply traditional principles of learning to instruction. Thorndike's principles of learning seem to be crumbling." The instructional feature designer may no longer be able to assume, for example, that immediate feedback (automatic cueing) will result in more effective learning in all training situations.

Likewise, the contractor may need to take responsiblity for performing the front-end analysis, rather than expecting to receive the information from the customer. Pohlmann, et al state that:

"It is inconceivable that one would expect a designer to design a flight training simulator without giving him (or her) a great deal of information about the intended instructional activities. Yet, it is apparent from inspection of numerous existing simulators, from review of simulator design procedures, and from review of the relevant literature that designers typically are given very little information about the instructional activities intended to be used with the device they are to design and the functional purposes of these activities."

Much of this problem can be accounted for due to the traditional role allocation: The customer is responsible for all of the front-end analysis, the contractor for the systems engineering. This situation is an idealism, not a reality. In order for the proposed model to work, constant feedback must occur between the customer and contractor, and both must take responsibility for data collection. If systems were perfect and all inputs were known and controllable, all processes known and intended, and no selection and distortion took place, then all outputs would be known and anticipated, and the system could be allowed to run with no mechanism to monitor its behavior (feedback). However, no system is perfect.[11] This is why it is imperative that the contractor employ personnel who are knowledgeable about current trends in education and training, and the government assign hardware software-oriented personnel to work with the contractor. Feedback cannot exist if both parties speak different languages.

CONTINUING DESIGN VALIDATION EFFORTS

The top-level flow chart (Figure 3) represents a model for use during the requirements definition stage for individual features. The contractor should also assess the overall effectiveness of the training equipment once the optimum design for the components has been derived. Adams[1] identified three applications for flight simulators: research, evaluation of performance, and training. "Research" implies the more "pure" science which was mentioned above, including transferability, perception, effects of cueing, etc. Evaluation of performance and training for the contractor must also be assessed through "applied" research. This may appear as an exercise in futility since the product has already been designed and is ready for use. However, the purpose is to collect more information to add to the training equipment data base for reference for future trainers.

Those conditions appear to place an extreme amount of responsibility on the contractor. However, the government must also play its part in providing more specific direction to the contractor regarding the product which is to be developed and in giving the contractor adequate time for developing the training equipment.[3] If this system is implemented to its fullest extent, then equipment requirements derivation will be less time-consuming in the long run as more information is being collected in the data base. Perhaps, then, the day will come when the contractor need only sit at the CRT, input the training requirements, and automatically receive the most cost- and training-effective equipment requirements and design.

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APPLICATION OF INSTRUCTIONAL SYSTEM DEVELOPMENT TECHNIQUES TO TEAM TRAINING

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ABSTRACT

Current instructional systems development (ISD) techniques are not well equipped to identify and effectively provide for team training requirements. While much research aimed at extending the ISD model to team training development is in progress, a systematic approach to meet near-term team training development needs is necessary. This paper provides an overview of an approach we have formulated and used successfully to this end. The approach is based on a functional analysis of the system goals/objectives which the team performance in question supports. The results are then represented systematically in a process model designed to capture the dynamic relationships between system conditions, and categorical team performances. The model is used to develop scenario-based exercise guides, similar to instructor guides for classroom use, but designed to provide instructor guidance regarding training device employment in the administration of effective team training.

INTRODUCTION

Methods for the systematic determination of individual skills are currently available. Training objectives (i.e., objective behavioral statements, conditions of performance, and performance standards/criteria) derived using these methods tend to be well defined. Subsequent training system development and implementation on this base is relatively straightforward. Collectively, these methods constitute the instructional systems development (ISD) model in all its manifestations (e.g., NAVEDTRA 106A/TRADOC 350, MIL-T-29053B(TD), MIL-STD-1379B, NAVEDTRA 110, NAVSEA OD 45519). Application of the ISD model to team skill determination, however, has not been equally effective. The literature attests to this observation repeatedly [1][2][3][4]. The principal difficulty, encountered early in the ISD process, lies in identifying team skills (or training requirements, or training objectives) with the same precision and objectivity as is possible with individual skills. As a result, the systematic measurement of team performance is elusive. Without systematic performance measurement, the provision of adequate feedback to the team is hampered. This inability to close the so-called training cycle by means of adequate performance feedback leads to inefficient and in many cases ineffective team training.

So saying, however, it is noted that the ISD model is one of the more useful developments of instructional technology. The intent underlying the model is to ensure the development of an effective training system. That is, one which provides trainees through its operation, the knowledges and skills necessary to meet the initiating training requirement. This is accomplished by the systematic application of defined planning, analysis, development, implementation, and evaluation procedures. The ISD model, however, is only a guide. Its virtue lies in the fact that it forces the systematic consideration and orderly development of each training system component. The principal drawback lies not within the model, but in the literal interpretation or uninformed application of the procedures described. This is particularly true with respect to team training development.

To counter this drawback, many efforts to formally extend the ISD model to team training have been reported (e.g., 4). For the most part, these have concentrated on the fundamental problems of team performance definition and measurement. Progress in these areas is apparent. For example, recent reconceptualizations of team performance [4][5] explicitly recognize the dependencies among individual and team performance, team tasks and the situation in which that performance occurs. However, while these efforts are promising, researchers in the area acknowledge that further conceptual work is required before specific team skills and their interrelationships can be isolated with the precision necessary for the derivation of explicit training requirements. Progress in the area of team performance measurement has also been reported. For example, Connelly and his associates have developed an approach which permits the evaluation of both team and/or individual team member performance in an ongoing mission context [6]. This includes specific tasks and task types. Again while the methodology appears promising, they point out that additional work in the area of generic task specification is required. Therefore, the systematic development of team training in the classic sense continues to be an elusive goal.

In the meantime, the quantity of resources which have been and are being committed to team training system and device development is large. The need for an ISD-based approach was never clearer. Our efforts in the area of submarine team operational training have made this point particularly clear to us. The lack of an ISD-based approach has led us to the formulation of an ISD-like process for team training material development, an overview of which is presented in this paper. The approach we took was pragmatic. Our intent was that it be based on ISD principles, that it accommodate findings of research yet to be completed, and at the same time that it provide a useful tool for the development of team training materials to meet the near-term requirement. It is based on the following four considerations.

BACKGROUND CONSIDERATIONS

First, ISD analytical processes grew out of a behavioral psychological tradition, focused on individual performance, and originally addressed operator and maintenance activities in well-defined (established) situations. While the distinction may not be exclusive, team performance in military systems is more accurately described as operational in nature, focusing on the functional objective the system (the equipment and the team personnel) was designed to meet. As such, team performance involves problem solving, resource allocation, and decision making processes on a different scale and in less structured, dynamic situations than for isolated individual activity. The atomization of performance when employing classical analysis methods tends to obscure the relationship of each component task or element to the overall system objective. This observation suggests an approach based on a functional analysis of the system and system objective of which the team to be trained is a part.

Second, the requisite individual skills collectively required to support successful team performance (in terms of the system functional objective) may be, and usually are, distributed differently among individual team members in different teams. Further, this distribution changes with experience. From the training development point of view, this makes it extremely difficult to specify generic team training requirements which are valid for all teams. That is, what is a correct procedural training requirement for one team may not be for a second team, though the second team may evidence the same summative performance deficiencies. The ISD model is not currently constituted to provide for this type of variability. Consequently, we formulated our approach to provide a training requirements structure within which team-to-team performance differences could be addressed flexibly. In so doing, however, greater emphasis is placed on the instructor's role. This consideration was also addressed in the formulation of our approach.

Third, the decision-making tasks at various levels within a team structure are action oriented, finite in number, and emphasize resource management. The key variables are associated with the information available (static and situational) on which to base a decision: amount, quality, rate, timeliness, and the set of alternative decisions they define. These are task conditions, not tasks per se. This suggests that an ISD-like development of team task listings should be relatively circumscribed with greater emphasis placed on the delineating conditions (operational situations) affecting the information flow and individual responsibilities/authority (formal and informal) within the team structure. (This is indirectly consistent with the observation that the stimulus-response behavioral basis of classical ISD analysis may not be suited to team performance analysis. Instead, a cognitive basis may be more appropriate. This mirrors the growing recognition of the shift in the field of learning psychology away from behaviorism toward a cognitive basis [7][8].)

Fourth, the administration of team training because of the dynamic, operational aspects of team performance, generally depends on an operationally realistic training environment. This is typically provided by conducting training exercises using a simulator or training device. These have become complex and costly, driven by the belief that team training transfer to the operational context is particularly sensitive to the fidelity of the training situation to the operational context. Certainly, the ISD process should play a significant role in balancing optimum trainer capability against cost. The process should not only define trainer functional requirements, but also provide a basis for prioritizing them, first in terms of the initiating training requirement, and second in terms of trainer/training effectiveness. This interaction is a rather sophisticated aspect of the ISD media selection process which is not fully documented. However, the instructor who must use the training device is, from our perspective, more important. As noted above, the instructor's role in team training is of considerably more significance than for individual training. The team trainees will be dynamically exercising previously learned knowledge and skills in support of the system functional objective. Student training materials are not a part of this process. Instead, the instructor monitors, evaluates, and critiques the team's performance and in general mediates the training process. This includes employment of the training device to best effect. For this, he requires guidance of a different nature than that found in instructor guides supporting classroom instruction. Further, it is not sufficient to train instructors to operate the training device only. In the same sense that, for example, a sonar operator must be trained in the operational employment of his equipment (i.e., in addition to Operator & Maintenance training) to realize its functional capability in the tactical context, so must the instructor be trained in the employment of his training device to deliver effective operational training. Therefore, the material provided for his support should guide his employment of the training device for effective team training during each training session or exercise. This aspect of team training system development is crucial. Further it can become quite involved, in effect requiring a mini-ISD development depending on the complexity of the team/system function, training device, and the number of instructors involved in its operation during a training session. Uninformed application of the ISD process often fails to adequately treat this aspect of operational training system development. Consequently, we formulated our approach to focus on supporting the instructor in his administration of effective team training.

PROCESS DESCRIPTION

Our approach to team training development recognized these factors. In particular, it explicitly recognizes the role of the instructor as the catalyst for effective team training and focuses on providing him with the necessary support. Accordingly, the principal product is an exercise guide, similar to an instructor guide, but differing in context and format. The approach involves seven steps:

- Data base establishment
- Exercise goal/objective development
- Process model development and operation
- Exercise selection
- Exercise development
- Quality control
- Validation

Activities involved in each step are described below in terms of a specific application to submarine piloting team training.

Data Base Establishment

Information on which the team training development process depended was gathered and consolidated in a data base. This information was organized in terms of general and platform-specific piloting procedures and guidelines, platform-specific navigation equipment as it pertains to piloting, the associated trainer capabilities and operation, training material requirements and specifications, and platform-specific piloting pipeline training. Analysis of these data established initial starting points for material development in three critical areas: (1) exercise goals and objectives, (2) material format and organization, and (3) instructional guidance. Subsequent development drew on this data base as required.

Exercise Goal/Objective Development

Exercise goal/objective development began with a top down, functional analysis of the piloting team/system objective. That is, navigation has been defined as the process of safely (standard) directing (activity) a ship from one point to another (platform operation). The activity of directing involves three categories of general team activities: planning own-ship track, repetitively fixing own-ship position, and evaluating fixed position against intended track as a basis for recommending own-ship maneuvers. While the general standard, team activity, and platform operation remain the same, the manner in which each general activity is performed varies as a function of details regarding the platform operation and conditions under which it is to be performed. For example, specifying that the platform operation is to be carried out in restricted waters (condition) identifies those specific activities which must be performed in each category associated with piloting, as well as the detailed standards to which each activity must be performed in order to safely complete the platform operation. As the first step in the exercise goal/objective development process, this type of general-to-specific analysis was performed on the data base, beginning at the piloting (rather than the more general navigation) level. Piloting team activities/standards in each of the three general categories, platform operations, and conditions were identified and organized. The process resulted in the following organization of information.

a. Platform Operation. The principal platform operation to be accomplished in a piloting situation is transiting from point A to point B. At point B the operation is completed at a specific geographic location such as an anchorage or a destination.

b. General Team Activity. The performance of a general team activity is required in accomplishing a platform operation. As for navigation in general, there are three of these executed repetitively during piloting operations: planning own-ship track, fixing own-ship position, and deriving recommendations for own-ship maneuvers from an evaluation of fixed position against intended track.

c. Condition. A condition is a factor affecting the manner in which the general team activities required to successfully accomplish a platform operation are carried out. Conditions were organized into three categories:

   i. Conditions affecting the accuracy with which own-ship's position is fixed such as bearing error, radar degradation, etc.

   ii. Conditions causing own-ship to deviate from intended track in the course of an operation, such as set and drift, contact encounters, propulsion malfunction, etc.

   iii. Conditions requiring accelerated performance rates and/or greater precision such as warnings of approaching danger, proximity to shoal waters, submerged operations, etc.

d. Exercise Goal. An exercise goal described the general training content. It is a descriptive statement which specifies the team to be trained, the platform operation which training supports, and the conditions under which the operation is to be conducted.

e. Specific Team Activity. A specific team activity is one that is required in accomplishing the exercise goal under the specified conditions. It falls within one of the three general team activity categories.

f. Exercise Objective. Satisfactory performances of the required specific team activities in an exercise are the exercise objectives. Satisfactory performance is determined by appropriate standards.

g. Standard. A statement of the precision, timeliness, and/or sequence with which a specific team activity must be performed under the specified conditions in order for the platform to safely and successfully complete the operation.

Process Model Development and Operation

The next critical step in the process involved development of a general model of the piloting process. The model, constructed during the analysis of operational information in the data base, describes the essential interrelationships among (1) platform piloting operations, (2) piloting team activities in each category, and (3) conditions. If a platform piloting operation (transit from point A to anchorage at point B) and a set of conditions (low visibility) are selected and provided to the model as inputs, the model will select the appropriate team activities which are required. Satisfactory performance of the selected activities thus becomes the behavioral objective of training. The standard for satisfactory performance is derived from successful accomplishment of the operation. In terms of an exercise, the selected platform operation and conditions determine the exercise goal and the exercise scenario. The model, operating on these same data, will identify the associated team activities required in order for the platform to attain the exercise goal. These activities, together with standards for their satisfactory performance, become the exercise objectives. The process thus resulted in the following organization of information.

Exercise Selection

Unlike the ISD model which addresses the selection of tasks for training at this point, our approach next focused on the selection of exercise goals, as defined above, for exercise guide development. This approach was taken because the team activities identified are recurrent and are common to most piloting situations. Therefore, the intent was to ensure that the resulting exercise set (22 as it turned out) was sufficiently broad to ensure the trainee team the opportunity to exercise specific team activities under all important piloting circumstances identified by the piloting process model.

Exercise Guide Development

The fifth step in the process was to choose an exercise goal from those selected in Step 4. An operational scenario was then constructed based on the goal and the associated conditions such that during the course of the exercise those team activities related to the objectives would normally be expected to occur. The scenario was then modified with respect to training device capabilities/limitations and annotated with required device control information. Training and performance evaluation information was then added with respect to scenario events. This information consisted of the required team procedures/performances, interactions, and outputs related to the selected exercise objectives. The draft exercise guide was then entered into word processing, reviewed for compliance with approved format specifications, and retyped in preparation for review.

Quality Control

The sixth step provided for quality control of the exercise guide materials. The draft exercise guide was independently reviewed for operational accuracy with respect to general submarine piloting procedure, platform operating information and operational training information contained in the data base. This review was performed by operationally qualified personnel whose only connection with the entire development was in the context of this review. The draft exercise was then reviewed for compatibility with the training device information. Modifications resulting from these reviews were incorporated, the exercise guide draft retyped as required, reviewed again for specification compliance, and prepared in final format for validation.

Validation

The final step in the development process involved exercise guide validation, as distinguished from verification. The purpose was to ensure that events controlled by the exercise scenario, display data, event sequencing, and data provided for training and assessment in the exercise guide corresponded to the actual data generated on the training device during exercise execution. Procedurally, this was accomplished by setting up the training device as required by the exercise guide and stepping through the exercise scenario in event sequence. At each step the training device was allowed to run in its normal training mode long enough to check the accuracy of the information presented in the exercise guide draft. The final activity involved incorporating all required changes determined in the validation process and preparing the exercise guide in final format for verification (pilot course training). In addition to actual exercise validation, this period was exploited for the purpose of definitizing instructor information requirements in the course of an exercise and definitizing the format in which the materials in general, and the exercise guides in particular, provided that information for instructor use. The materials were then piloted in an actual course, minor modifications incorporated, and subsequently delivered for Navy use.

DISCUSSION

The process described herein is presented as an approach not a model. It represents an extension of ISD principles. Further documentation of guidance regarding tailoring of the approach to particular applications (e.g., other teams) is required. For example, the procedure for developing process models, a key feature of this approach, requires full explanation. What is presented here represents only an overview. Further, our approach does not intend to answer outstanding questions regarding the theoretical aspects of team performance as related to training. It does, however, provide a workable framework within which these answers can be incorporated into team training development as they become available. In the interim it provides a basis for developing effective support for the team training instructor. The approach has proven useful in eight different applications to date involving the development of instructor materials supporting both shorebased and shipboard team operational training. The products -- exercise guides -- have been well received as indicated by feedback from the end user.

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COLLECTIVE FRONT-END ANALYSIS: A MISSION-BASED APPROACH

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ABSTRACT

Collective front-end analysis is the process by which the critical missions and collective tasks of a battalion are specified. Collective tasks are units of work requiring two or more people for their completion. A mission-based approach is employed in CFEA. The CFEA process begins with specification of a battalion mission, proceeds to specification of battalion element missions, and ends with delineation and description of collective tasks. The mission-based approach to CFEA is advantageous because it helps ensure a thorough listing of a unit's collective tasks and provides a means of relating task criticality directly to a unit mission. In order to reduce the workload on the user and help organize the massive amounts of data involved, user job aids were prepared.

INTRODUCTION

Most scenarios for full scale confrontation between the United States and any of its major adversaries describe a "come as you are war" in which the U.S. will have to fight immediately without the luxury of a lengthy mobilization period as enjoyed in previous wars. This rapid response environment in which U.S. forces must exist requires that fighting units establish and maintain high readiness levels. An important factor influencing a unit's readiness is the training it receives. Development of effective unit training is predicated upon the ability to identify performances that are critical to accomplishment of the unit's mission. Among the performances that support accomplishment of a unit's mission are many tasks that require teams or collectives of personnel for their performance. Traditionally, front-end analysis efforts have failed to address collective tasks or have addressed them inadequately. As a result, training of collective or team performance in units has suffered.

Recognizing the importance of team performance to unit readiness, the Army has recently been concerned with developing a means of identifying collective tasks. As defined by TRADOC PAM 310-8,[1] collective front-end analysis (CFEA) is the process by which the critical missions and collective tasks of a battalion are specified. This paper provides a brief description of an approach to CFEA, discusses issues pertaining to application of CFEA, and describes job aids used in the CFEA process.

APPROACH TO CFEA

A battalion is a large organization and one would expect its personnel to perform a large number of collective tasks. A method for delineating collective tasks is needed that can offer some assurance that a thorough listing of collective tasks will be provided. Once the collective tasks in a unit have been specified, those performances must be evaluated to determine which ones warrant the expenditure of training resources. An important factor determining the need for training a task is the extent to which deficiencies in task performance influence outcome of a unit mission. Thus, the method employed to derive a unit's collective tasks should allow for determination of the relationship between a given task and a unit's mission.

An approach to CFEA has been adopted that addresses both of the above problems. The approach to CFEA is described as mission-based. It is described as such because the mission of the unit to be analyzed is taken as the point of departure for the analysis. The CFEA process employs techniques of systems analysis[2,3] and begins with specification of the unit mission(s) or objective(s), proceeds to specification of battalion element missions, and ends with delineation and description of collective tasks. The process is organized into two major phases: the mission analysis and the task analysis. Figure 1 presents the major steps involved in CFEA. Figure 2 depicts the relationship between the major products of CFEA and the phases of the analysis. A brief description of the CFEA process is provided below. A discussion of the advantages of the mission-based approach follows.

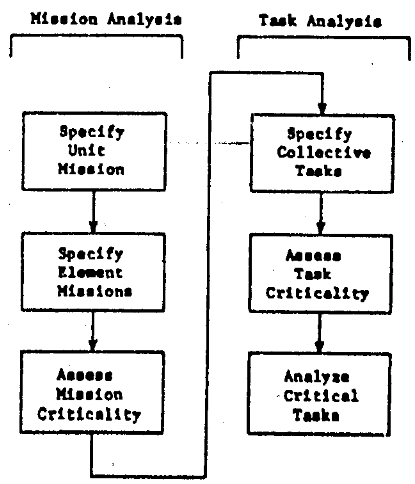

Figure 1. Major Steps in CFEA

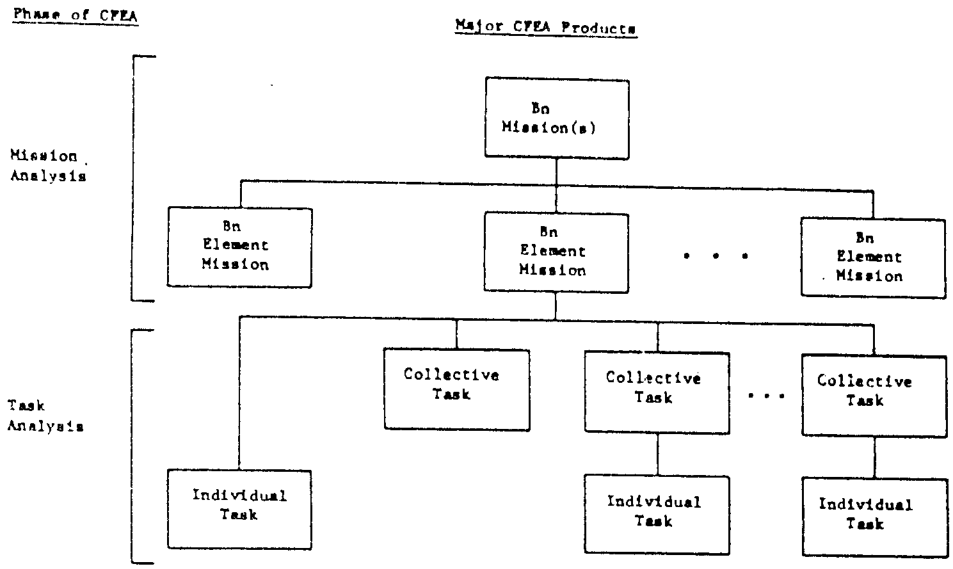

Figure 2. Relationship of Major CFEA Products and Phases of CFEA

The CFEA Process

As indicated in Figure 1, the mission analysis begins with development of mission statements that describe the objectives of the unit under analysis. Statements are formulated that reflect the capabilities of the unit's personnel and equipment (e.g., the mission of an air defense battalion would be to provide low to medium altitude air defense) and requirements imposed upon the unit by its parent organization (e.g., a unit attached to the Rapid Deployment Force would have the mission of rapid deployment via air or sea).

Once the unit's mission has been established, attention is turned to specifying the missions performed by each of the unit's organizational elements as they support accomplishment of the unit mission. Specification of element missions is accomplished by determining the types of functions that are required to accomplish the unit mission (e.g., plan, direct, engage, service, repair, rearm, refuel, feed, etc.), describing the organizational structure of the unit, and allocating the different functions to organizational elements. For each element, a statement or series of statements are prepared that describe the specific nature of the function(s) performed by the element.

After battalion element missions have been specified they are assessed to determine their criticality. Criticality of a battalion-element mission is primarily a function of three factors: its direct effects on the battalion mission, its effects on the ability of the battalion to sustain operations and its effects on ability of the battalion to survive on the battlefield. If failure of a mission affects unit functioning in any of these areas, the mission is deemed critical.

When the assessment of mission criticality is complete, the task analysis phase begins. This phase consists of three steps. First, each critical battalion element mission is analyzed to determine the collective tasks that support it. Derivation of collective tasks is accomplished by describing all of the activities that are involved in performing a given mission, grouping the activities into units of behavior constituting tasks, and determining which are performed by collectives of personnel.

Next, the collective tasks are assessed to determine their criticality for training. A primary factor affecting a task's criticality is its influence on the battalion element mission it supports. Tasks whose success or failure affect mission success are considered for training. Tasks that are difficult or hazardous to perform, or are performed infrequently and easily forgotten are given high priority for training.

Finally, critical tasks are subjected to a detailed analysis which produces operational sequence diagrams (OSDs).[4] Operational sequence diagrams display the flow of task performances and the interactions among performers. Task conditions and standards are specified in the same manner as for individual tasks.

Advantages of the Mission-Based Approach

The major products of CFEA are the battalion mission(s), battalion element missions, and collective tasks. These products are used to develop Army Training and Evaluation Plans (ARTEPs), drills, and other training materials. Studying relationships between CFEA products depicted in Figure 2, several features of the mission-based approach to CFEA are apparent. First, development of mission-oriented training is facilitated because the tasks that support a given mission are specified. Second, because the starting point of the analysis is a battalion mission, it is assured that all subsequent products are mission relevant. Third, breaking the battalion mission into battalion element missions prior to specifying collective tasks helps ensure a thorough listing of tasks. The battalion element missions provide a means of subdividing the area in which the search for collective tasks occurs. Each battalion element mission focuses the task analyst's attention in a circumscribed area, decreasing the likelihood that important tasks will be overlooked. Finally, the mission-based approach to CFEA allows for a more accurate assessment of task criticality. The relationship of a particular task to a battalion mission can be traced through the battalion element mission that the task supports. A task's criticality can be determined by jointly considering the criticality of a task to the battalion element mission it supports and the criticality of that battalion element mission to the battalion mission.

It should be noted that the traditional job-based approach to front-end analysis does not offer the benefits of the mission-based approach. In the job-based approach the task analyst attempts to inventory the tasks performed in a given job. Use of a job-based approach to CFEA would result in a thorough listing of tasks only if the jobs in the unit combine to fulfill all of the unit's requirements for successful functioning. This situation is probably not the case given the fact that jobs in most units have evolved as a function of equipment utilized or changes in unit structure rather than on the basis of requirements dictated by a unit's mission. Further, the assessment of task criticality is more difficult in the job-based approach because the relationship between collective tasks and a battalion mission cannot be traced explicitly. Finally, because missions and the relationships between missions and tasks are not specified in the job-based approach, mission-oriented training cannot be developed.

ISSUES IN CFEA APPLICATION

Ultimately, the objective of CFEA is to provide inputs for development of training programs that will enable a unit to perform its mission. There are, however, issues regarding conduct of CFEA that impact the products generated and, hence, the training programs subsequently derived. Review of training materials that use CFEA products (e.g., ARTEPs) indicates there is disagreement over what constitutes a collective task. In addition, there is some question as to the proper scope of CFEA. Both of these issues are discussed below.

The Need for Precise Definition of Collective Tasks

The effectiveness of training programs developed using CFEA products is partly dependent upon how precisely the performances to be trained are specified. In preparing collective task statements users should give careful consideration to the definition of a collective task. Proper collective task statements should reflect units of work that are performed by two or more people, have a definite beginning and end, and have purpose in and of themselves.

All too often, however, it seems that collective tasks have been confused with collections of tasks. For example, in a recent Army Training and Evaluation Program (ARTEP) one of the collective tasks listed was to perform periodic checks. Periodic checks is a class of preventive maintenance tasks, some of which are performed by individuals and some of which are performed by collectives. Such task statements are inappropriate for training development purposes because they are not specific enough and must be further analyzed in order to determine what is to be trained. In an effort to aid specification of collective tasks, a set of criteria for evaluating performances is offered below.

When developing collective task statements the analyst should review each performance under consideration and try to specify its start and end points. If these points can be determined, the statement does reflect a task. Next, the analyst should examine the task to ensure that it is in fact a collective as opposed to an individual task. There are several circumstances that give rise to collective tasks and the analyst should determine whether any apply to the task under consideration. First, some tasks require use of skills found in two or more specialties. Other tasks require simultaneous performance of task steps in different locations. Finally, performance of a task can require such a large number of skills that it would be impossible for one person to perform the task in a timely or otherwise effective fashion. Activities meeting these criteria are collective tasks.

The Scope of CFEA

The stated objective of CFEA is to specify and describe collective tasks. Unfortunately, if the scope of CFEA is limited to specifying collective tasks, important individual tasks that support accomplishment of a battalion element mission may be overlooked. The relationships between missions and collective and individual tasks are depicted in Figure 2. Note that in some instances collective tasks are composed of individual tasks. In others, individual tasks do not support collective tasks but stand alone in direct support of a battalion element mission. Many maintenance, administrative, and supervisory tasks, for example, are performed by individuals. Therefore, the objective of CFEA should be to specify all of the performances (both collective and individual) that support accomplishment of a battalion-element mission. This orientation to CFEA will enable development of training programs that support all aspects of mission performance.

CFEA JOB AIDS

Given the size of the units analyzed and the massive amounts of data that are generated, CFEA can seem overwhelming to a task analyst. In designing a process for conducting CFEA, an objective has been to provide procedures that can be readily employed by Army training developers. Development of procedures was based on recognition of the fact that front-end analysis is a somewhat subjective process that cannot be algorithmized to the extent that the task analyst need not make decisions or judgments. Given that some decision making is required in CFEA, the concern was to design procedures such that the amount of information to be manipulated by the user at any one point in the process is minimized. This was accomplished by breaking the process into steps and developing job aids whenever possible. As in other training development and evaluation processes such as the Training Developer's Decision Aid (TDDA)[5] and the Training Evaluation and Cost Effectiveness Program (TECEP),[6] job aids were developed for CFEA to facilitate organization of data and decision making. Examples of two job aids used in CFEA are presented below.

As many as 150 to 200 battalion element mission statements might be generated in a CFEA. The process of developing this many mission statements can be time consuming and tedious. Also, because of the large number of element missions performed in a battalion, it is easy to overlook some. In order to speed the process of specifying these missions and to help ensure thorough coverage, CFEA users are provided with a matrix of job aids. The job aid includes a list of generic functions which serve as prompts for developing mission statements. One job aid is for specifying classes of mission functions that apply to battalion elements. Mission function classes are major groups of functions that are performed in support of battalion missions. The three mission function classes used in CFEA are combat operations, support, and survival. This job aid, presented in Figure 3, consists of a battalion element by function class matrix. The user enters 'X's into the appropriate cells of the matrix to indicate the function classes that apply to each element.

Mission Function Classes

Bn Elements	Combat Operations	Support	Survival
Bn Hq	X	X	X
OP/INTEL	X		X
Fire Direction	X	X	X
Admin.		X	X
Transportation		X	X
Medical		X	X
Motor Maintenance		X	X
Base Fire Platoon	X		

Figure 3. Illustration of Allocation of Battalion Elements to Mission Function Classes

Next, elements identified as performing functions of a given class are compared against the functions that make up that class. Once again, a matrix job aid is used to identify and record the functions performed by each element. An example of such a job aid used to relate functions to elements of an air defense battalion is provided in Figure 4. Finally, specific statements of element missions are developed using the generic functions designated in the Figure 4 job aid as a point of departure.

Support Functions

Bn Element	Rearm	Refuel	Service	Repair	Transport	Resupply Materiel	Supply Power
Fire Direction			X	X			
Bn Supply	X	X				X	
Motor Maint.		X	X	X			X
System Support Plt.	X		X	X			X
Transportation					X		

Figure 4. Example of Allocation of Battalion Elements to Functions in a Mission Function Class

While it is true that actual specification of battalion element missions requires some judgment or creativity on the part of the analyst, this process is facilitated by use of the job aids which prompt development of mission statements. In addition, generic function lists presented in the job aids help provide a thorough listing of element missions because they serve as cues for the recall of missions. Finally, use of these job aids is important because of the manner in which they control the user's attention. The cells of a given matrix force the user to consider in isolation each element in conjunction with each function. Thus, the amount of information to be considered by the user at any point in the process is minimal and the likelihood of a thorough listing of missions is enhanced.

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UNDERSEA WARFARE TRAINING AND READINESS ASSESSMENT SYSTEM REQUIREMENTS

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ABSTRACT

Manpower and resource constraints over the next decade will force a reexamination of Navy training methods. One change that can be predicted is a shift in emphasis from maintenance to operational training as advancing technology leads to more maintenance-free systems with greatly enhanced functional capabilities. To assist in training approach trade-offs, a better definition of the overall training system is required as well as a statement of training system operational requirements by warfare area. To illustrate, an operational requirement is suggested for undersea warfare and the conclusion is drawn that increased emphasis should be placed on organic, onboard approaches to training as substitutes for current shoreside training methods.

Training is the single most important function in which the military services engage during peacetime. To the term "training," should be added the phrase "and readiness assessment" because training by itself is incomplete unless there are methods of measuring the capabilities of trained forces to wage war. My thesis is that within the Navy in general but, more specifically, within the field of Undersea Warfare, the capabilities to train and assess readiness can be improved.

That there are problems is due to many factors. Manpower availability of the proper quantity and quality, the characteristics of our weapon systems, the types of tools available for training, organizational attitudes toward and perceptions of the nature of the problem, are among those included. One factor which does not appear high on the list of problem contributors is insufficient financial resources. The dollars are there. It is how they are applied that can be improved.

There are five thoughts central to my argument which will be expanded upon during the balance of this paper. They are:

- Constraints on manpower and resources will continue to grow during the next decade, forcing a continuing reexamination of training methods.
- In Undersea Warfare, the Training System is a "system" in only the loosest sense of the word.
- Evolving technology will provide a shift of emphasis from maintenance training, a historical concern, to operator/tactical training, the principal problem of the future.
- Rational training system trade-offs are not possible in the absence of a top level statement of Operational Requirements.
- An Operational Requirement prepared by persons knowledgeable in the Undersea Warfare field will lead to greatly increased emphasis upon organic, onboard, training approaches.

We Americans can have amazingly short memories. Consider, for example, popular attitudes towards energy as a national problem between the time of the oil embargo of 1973 and the glut of 1982. Then it was a crisis. Today we hear little of the explosive rhetoric of the early 70s, yet the basic problem remains. There is an interesting parallel between the national attitudes toward energy just noted and toward the availability of military manpower. It is important that we share a common perception of the manpower situation today and of future trends because of the importance of such projections to the Navy's future training system.

Two years ago, manpower problems in the Navy approached crisis proportions. Recruiting goals were not being met and retention statistics were appalling. It was not uncommon to read news items about ships which could not operate because of personnel shortages. Fortunately, national attitudes were strongly pro-defense and the Congress reacted with considerable dispatch to enact much-needed pay legislation. The desired effects were achieved and the manpower ebb was halted.

I have nagging doubts, however, as to whether the reversal is permanent. How much has the recession contributed to improvements in recruiting and retention? How much is the improvement due to a national conservative swing to the right, a movement which appears to be moderating as the issue of military program vs social programs, guns vs butter, intensifies? How much confidence should be placed upon historical data gathered since implementation of the All-Volunteer Force, data that indicate that while every pay raise has produced a peak in manpower numbers, each subsequent trough between peaks has been deeper than its predecessor. Whether history will repeat itself is uncertain.

There is little cause for optimism, however, because there are at least four factors which will tend to aggravate an already shaky situation. First, we face a shrinking manpower pool of 18-year olds for at least the next ten years. There has been enough written on that subject that further amplification should be unnecessary. Second, as the 600-ship Navy goal is progressively reached, overall manpower requirements will increase even further. Third, the trend toward more sophisticated weapon systems designed to provide a sufficient margin of performance advantage to offset Soviet quantitative advantages has impacted the Fleet petty officer intensity, that percentage of enlisted men who are rated. An increased petty officer intensity tends to translate into a growing training pipeline. During 1981, the pipeline absorbed 21 percent of Navy manpower and was growing at a rate of one percent per year. That 21 percent translated into a 2 billion dollar annual investment. Lastly, accelerating technological change in the civil sector is of real concern.

The microelectronics industry has felt the impact of the recession less than other industry segments. It is inevitable that as the economy heats up, the commercial electronics, data processing and communications industries will undergo a veritable explosion and, in the process, create major demands for technical manpower. Such demands must be supplied from that same manpower pool which supplies Navy needs.

Rounding out the earlier analogy, the critical manpower situation of two years ago corresponds to the 1973 oil embargo. Today we may be in that somewhat complacent period caused by the apparent availability of adequate resources - the temporary oil glut of 1982. In reality, however, if all factors were considered, the long term manpower picture, just as in the case of energy, looks pretty grim.

Turning now to the second of the five points, upon entering the Navy, each new member becomes part of a very large and comprehensive training system which affects every aspect of his Navy career. This training system can be classed a "system" in only the loosest sense, as stated previously. It did not derive from the normal system development process where, first, requirements were defined and system functional characteristics were derived by trading off alternative solutions to the stated problem. Rather, the system just grew. It evolved from a variety of individual responses to individual problems over many years. Rarely, if ever, has there been an attempt to analyze the entire system as a whole. The system is huge. It almost defies analysis because of its size, which has been part of the problem. However, analysis as a system is a "must" requirement. Ever-increasing demands for support will not be satisfied as competition for such resources grows. Trade-offs between alternate solutions will be necessary. For that purpose, a better definition of the training system and all its parts is required.

Since training impacts manpower, equipment, and operation, it is not surprising that the training system has grown to be quite complex and that many organizations have training-related responsibilities. In Undersea Warfare alone, time does not permit the listing of all the organizations involved, but an inspection of Figure 1 which addresses only ASW and Atlantic Fleet activities for simplicity, illustrates some of the management complexities involved. While the roles and contributions of the organizations of the Chief of Naval Education and Training and of the Fleet Commands are widely appreciated and understood, there are existing organizational elements and expanding functions within the Navy Material Command which have a major role in training which may be less well known. Included in this latter category are those organizations responsible for underwater ranges, targets and for training capabilities embedded in weapon systems under development.

The Atlantic Undersea Test and Evaluation Center may have had its origins in the development, test, and evaluation of underwater weapon systems but its contribution to training and readiness assessment through the monitoring of SHAREMS and MiniWars and in SSN/SSBN PCO training has grown significantly. Also, the scarcity of submarines for target services has placed increased emphasis and dictated growing resource requirements for such tools as the Expendable Mobile Acoustic Training Target, the target Mk 30 and its potential successor. the Advanced ASW

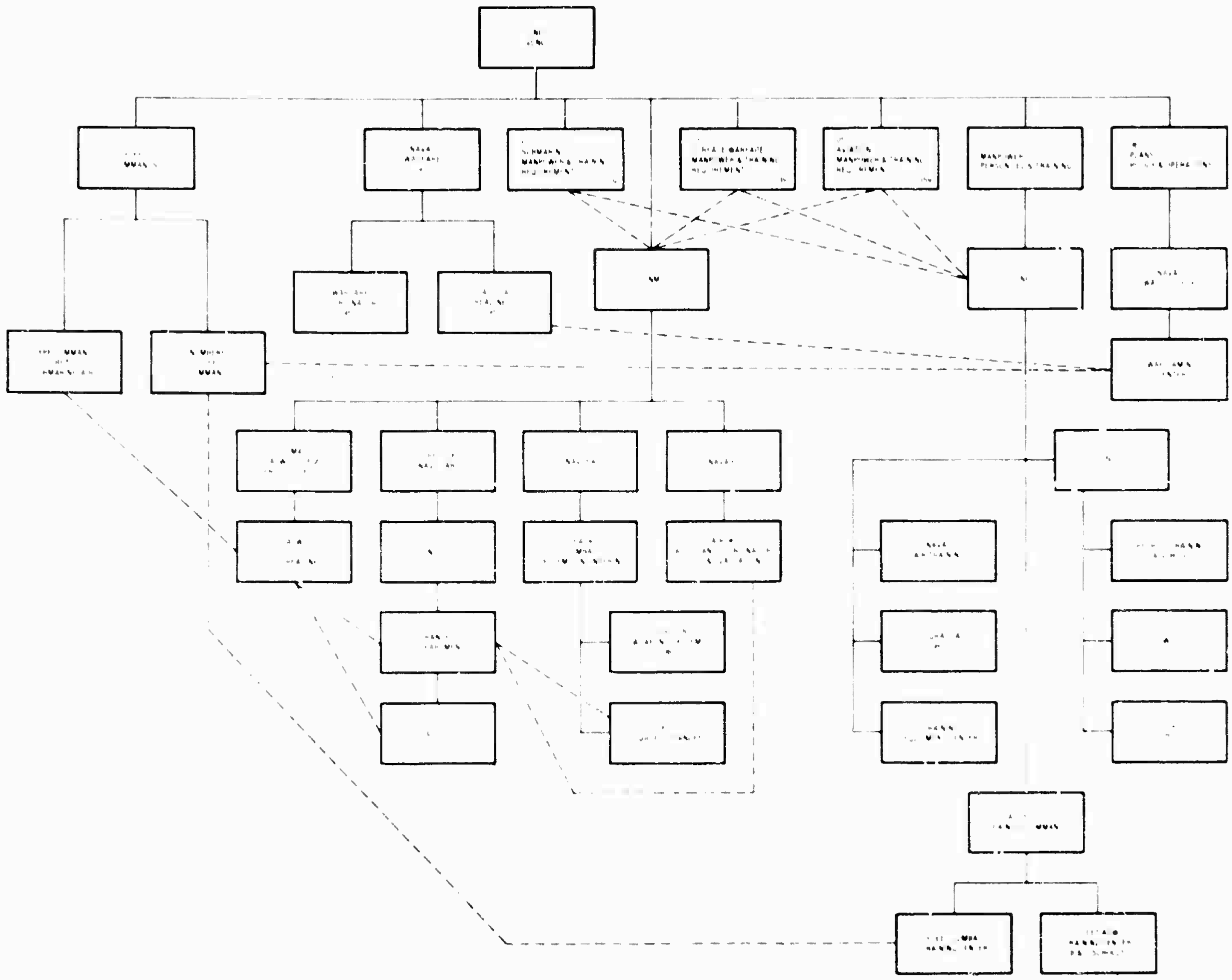

Figure 1. ASW Training - Interested Organizations

Target. Lastly, evolving silicon technology, and in particular microprocessor/microcomputer families coupled with low cost memory, has made it possible to either add onto or to embed training tools in systems already in the Fleet or entering system development. In the former category falls the AN/BQR-T4 installed in the Poseidon-class SSBNs, and the AN/SQS-T5 slated for the Aegis-class cruisers. In the latter category are found the embedded target stimulators of the Submarine Active Detection System now in engineering development and the planned organic trainers for the DD-963 and FFG-7 class AN/SQQ-89s and for the SSN-688s beginning with SubACS Phase 0 in SSN-751.

All of the above activities either complement or duplicate the training functions normally falling under the auspices of the Chief of Naval Education and Training. While there may not appear to be competition for resources because they may be funded from different line items, realistically their contributions to training and readiness should be measured by a common yardstick. Such assessment will continue to be very difficult until a better system model of the overall training system can be formulated.

As I stated in my third introduction point, historical needs for maintenance training will moderate and be replaced by increased requirements for training in operations and tactics. Systems decisions have already been made that will reduce the need for maintenance training. This fact may be difficult to accept by an operator in the Fleet today saddled with the difficult task of keeping an older equipment on line, one which is neither modular in design nor equipped with built-in fault detecting and localizing capabilities. As the newer generations of equipments are being fielded, however, maintenance actions consist of plug-in replacement of modules in response to system-generated instructions. For systems such as SubACS which will appear in the Fleet in the latter half of the decade, system design requirements specify a sixty-day maintenance-free mission, thus eliminating even the simple module replacement maintenance actions noted above.

That these changes are fortuitous is an understatement. With the manpower projections cited earlier, the Navy would be unable to man its ships, if prior maintenance design practices were carried forward to systems of the future. The day of the electronics "super tech" who could make onboard module repair and jury rig a failed system into some form of operation is disappearing, if not already gone. Advancing electronic device technology leading to dramatic increases in functional complexities and densities has moved the field beyond the levels that can be taught in A, B, or C schools. There may be super techs in the future but they will be found at Intermediate Maintenance Activities (IMA) and will probably be called "engineers".

Rather than bemoan such changes as some may, we should be thankful. The positive growth rate of the training pipeline over the past years should slow and eventually reverse. I argue that even now there are sonarman A-school graduates who have no need for a ten-week course in basic electricity and electronics for the systems to which they will be assigned. Why teach it, if it cannot be employed? Do we really need to teach soldering techniques? I shudder to think of the damage that a misguided soldering gun can produce to a multi-layer, high density standard electronic module, or to a power supply or wiring backplane. I am convinced that maintenance training should be confined in the very near future to the reading of fault indicators and simple module plug-in substitution for repair.

While maintenance training requirements may decrease, the need for operational/tactical training and for readiness assessment is increasing significantly. The Navy's response to quantitative inferiority in submarine numbers, for example, has been to maintain a significant qualitative performance superiority. ASW combat teams of fewer men are controlling systems with more functional modes, weapon mixes of greater variety and larger action areas than would have been thought possible just a few years ago. Towed arrays, Lamps III, Harpoon, Tomahawk, over-the-horizon targeting are just a few of the many new tools whose efficient application our operators of the 80s will need to master. The training burden will be large.

Up to this point, I have sketched a picture of increasing manpower problems with a shift in training requirements emphasis from maintenance to operations and tactics. Also, I have stated that the training system which must take scarce manpower resources and transform them into war-fighting capable teams is not completely modelled. This makes trade-off assessments of competing proposed modifications to the system quite difficult. My fourth point is as follows: In order to clarify the training system model and to assist in the important resource allocation trade-off process, top-level training system operational requirements, by warfare area, are needed. Let me illustrate what I mean by "top-level" by a suggested version of an operational requirement beginning with a statement of objective.

<u>The objective of a training system is to prepare Fleet personnel, as individuals and as teams, to perform effectively in the operating environment and to measure combat readiness of both equipment and personnel.</u> Each warfare area has unique requirements which must be satisfied if the overall objective is to be met. In undersea warfare the key requirement is to <u>teach interpretative analysis skills as well as operating procedures.</u>

There is a significant difference between knowing how to operate equipment, ships, and forces and how to use such resources to achieve an operational objective. Most training systems concentrate on the procedural aspects of operations training and neglect the more difficult training challenge which is how to interpret and evaluate the contribution of each element of the system to the solution of the overall problem. Interpretative skills weigh heavily in undersea warfare in contrast, for example, to surface ship anti-air warfare.

The highly complex underwater acoustic environment, the low speed of sound in contrast to that of electromagnetic energy, and the low speeds of acoustic targets of interest relative to those of aircraft and missiles result in tactical problems which evolve over minutes and hours rather than in seconds. The processes of detection, classification, localization and weapon control are very dependent upon team skills in analysis and interpretation of data which are not provided with the precision, uniqueness, and rapidity of radar. In contrast, the speed with which the AAW problem develops with potentially threatening targets measuring in the hundreds at any point in time, points to system operation which is procedure dominated. Threat assessment algorithms and rules of engagement must be predetermined. There just is not time for extensive interpretation and analysis, for the reorientation of forces or the placement of new sensors nor are such steps needed. I do not mean to infer that procedural training is unnecessary in undersea warfare. To the contrary, procedural knowledge is very important. Without training in equipment operation, communication protocol, and tactical constraints, as examples, a single platform ASW team or a multi-platform task group cannot begin to function. In fact, the knowledge of proper operational procedures must become second nature. Too often, however, training in undersea warfare stops at procedural training (the tip of the iceberg of the overall undersea warfare training problem) and ignores the far more difficult aspects which are the teaching of interpretative and analysis skills.

The second most important requirement is to provide rapid, accurate assessment of system and team performance following a training event. This requirement is not unique to undersea warfare and should be a characteristic of our training systems, independent of warfare area. Training without prompt, accurate feedback may do more harm than good by developing a false sense of accomplishment on the part of participants when, in fact, the objective of the exercise is not accomplished. Again procedural training is relatively straightforward, and performance assessment can be accurate and rapid with proper monitoring. Overall performance assessment involves determining whether proper interpretations of available data were made and appropriate actions initiated. This is far more diffi ult. It requires a truth table (an accurate navigational plot of the positions of all platforms, sensors, targets and weapons) and a means of comparing this truth table with what the exercise participants thought had occurred.

In keeping with the earlier statement that maintenance training requirements are decreasing and will continue to do so in the future, the training system should teach only the minimum maintenance skills consistent with organizational level support requirements.

With the steady growth in operating demands upon our submarine forces, it is not surprising that to make minimum demands on submarine services as targets should be a priority requirement. While it is unrealistic to believe that the need for submarine services for exercise targets can be eliminated, alternate approaches to employing operating submarines as targets must be developed if we are to maintain a reasonable state of readiness in ASW.

Experience has also shown that the provision of frequent training opportunities is an important requirement. A trained operator or team must practice regularly to keep developed skills. This has been demonstrated by tests of SSBN sonar operators during operating patrols and probably applies to other members of the ASW team. Since funding and other constraints will probably continue to limit ship underway and aircraft flight time, it is imperative to use every opportunity to exercise and train. The meaning of the term "frequent" should depend on the perishability of the developed skills as well as measured performance on previous exercises. It definitely is not the one or two-year gap often experienced by frigates in conducting a multi-platform SHAREM or MiniWar nor the quarterly opportunity VP air crews receive to drop one actual torpedo.

Another requirement is that the training system be transparent to the operator, that is, is indistinguishable from a true operating system. This requirement can be interpreted two ways. First that any simulated/stimulated targets or displayed information have perfect fidelity with the real world and, second, that in addition, operators are not alerted and do not suspect that an exercise is in progress. The former is considered of principal importance when the training operation is striving to develop evaluative and interpretive skills. While there are occasions when it is desirable to test the state of operator alertness, that testing is rated considerably below the requirement for realism. Realism also implies that training exercises avoid stereotyping to where team participants recognize a repetition of a former event.

It is also clear that the capability to train at all levels of the team -- the individual sonar operator, the sonar team, the combat system team is a requirement. Any significant investment in a training system must support all levels of team participants -- individuals as well as groups.

Another desirable attribute is to impose no geographic constraints. Geographic independence is important. To limit the area constrains accessibility to training and may imply a restrictive range of ocean environmental conditions.

A problem that has occurred in past training systems is performance inconsistencies between the equipment used for training and that employed in Fleet use. It is an important requirement that consistency between equipment used for Fleet operation, and that upon which training occurs be provided. Differences can result from unintended breakdowns in system configuration management during equipment evolution and development or from deliberate efforts to save cost through the use of inexact simulations of actual system hardware. Such differences may detract from the effectiveness of training exercises. What is more important, however, they could constitute distractions during time of stress during actual operations.

Nine requirements statements have been listed. There may be others which experienced personnel in the field can add. The list may require modification. The specific details are not as important as the existence of some formal statement of requirements to facilitate system trade-offs and the resource allocation management process.

The statement of requirements just developed provides positive support for the fifth point of my argument that organic, onboard, training approaches should receive increased emphasis. Consider with me how each of the operational requirements just listed can be satisfied most logically by onboard training approaches and the attendant, very real benefits which can accrue.

Requirement 1 - Interpretative and Procedural Skills. To properly develop interpretative analysis skills requires environment models which faithfully represent all of the complexities and infinite variations in ocean acoustic propagation and in background noise and reverberation from both natural and manmade sources. The required degree of realism can undoubtedly be created artificially but at tremendous expense for development and operation. Normally the latter implies limited accessibility because only a few complex and expensive systems can be afforded. The counter to the expensive ocean simulator is to use the ocean itself by mixing artificially generated threat data with the normal information detected by ship's sensors.

Procedural training, on the other hand, does not require exact realism in environment modelling. Simple models can be embedded economically in sensor systems to support procedural training in port. Some may suggest that portable van-installed systems located in major fleet centers can provide the function described. Procedural training in port could be satisfied by such an approach although front-end target injection by a portable system may be a poor choice, because of the susceptibility to electrical interference of the early processing stages of sonar sensors. The van systems, however, will fall short in realism for interpretative training nor will they satisfy the needs of ships on extended deployments such as those in the Indian Ocean who now are suffering from a lack of ASW training opportunities.

Requirement 2 - A Truth Table. A principal limitation from which onboard training efforts have always suffered has been the inability to provide rapid, accurate feedback on ship performance following a training exercise. The greatly expanded use of range facilities such as AUTEC has been motivated by this requirement. While the ranges have the ability to accurately measure performance, feedback has not always been rapid. "Hot Washups" and "Quick Look" reports designed to quickly disseminate information may have benefited Command levels but have not been sufficiently detailed nor prompt to be of value to the working level members of the ASW team.

The Post-Operational Analysis and Exercise Review Program, acronym PACER, developed for use initially on the BARSTUR Hawaiian Range, was designed to correct the above deficiency. PACER provides a critique to participating units within three days of an exercise which consists of a narrated, pre-edited and time-compressed video replay of 3-D range tracking data merged with shipboard target motion analysis data. The program has been very effective and similar efforts are being applied at other ranges.

As valuable as current instrumented ranges and exercise feedback systems are, they do suffer from limited accessibility. The average ship might expect an opportunity only once a year to exercise on range. In contrast, an organic trainer with embedded target injection capabilities provides the same benefits for target detection, classification, target motion analysis and weapon direction functions as an instrumented range and a PACER system without the availability restrictions. The only function not covered is live weapon firing. Torpedo weapon firings are not normally conducted in the open ocean because of the need for retriever services and most firings occur on the instrumented ranges. If, however, retriever services are available, there are techniques which support weapon firing in an open ocean exercise while employing an organic trainer.

Requirement 3 - Maintenance Skills. With maintenance at the organizational level confined to module substitution, onboard training is practical. A variety of new tools such as the interactive video disk can provide training support. A video disk/sonar display marriage would permit individual operator maintenance training during non-battle conditions when underway or in port when manning of all consoles for routine operations is not a requirement. The interactive video disk coupled to system sonar displays should also eliminate maintenance manuals as we know them today.

Requirement 4 - Minimize Submarine Service Demands. An onboard training system based upon artificial target injection is obviously in keeping with this requirement. There are, of course, alternate approaches possible such as expendable or reusable mobile training targets. All existing and planned targets such as the Mk 38, EMATT, the Mk 30 or the Advanced ASW Target suffer as combat system training targets because of the technical difficulty of achieving acoustic fidelity or tactical realism. In order to provide some form of target azimuthal extent, for example, it is necessary to tow multiple transponders to produce highlights. Towed arrays complicate system design as well as the launching and retrieval process while still providing less than perfect target realism. The faithful reproduction of submarine low frequency radiated tonals is also quite difficult within transducer size constraints which are practical for expendable or torpedo-sized targets. The speed and depth characteristics of current threat targets are also a challenge to emulate. Onboard target stimulators suffer from none of the above limitations. High fidelity target signatures and realistic target motion dynamics have been demonstrated repeatedly.

Requirement 5 - Frequent Training Opportunities. Organic trainers usable underway and in port certainly satisfy this requirement better than centralized facilities which require transport of teams to training sites. In addition, ensuring the availability of all appropriate members of a team to be trained can be a very real challenge because of conflicting personnel requirements when a ship is in port.

Requirement 6 - Training System Transparency. As was noted previously, this requirement can be interpreted in two ways. First, there is the requirement for high fidelity in order that operators in training to detect and classify underwater targets not do so based uupon some misleading artifact of the simulation which would not appear in the real world. Considerable development effort has been applied to this area for training systems now in use by the Navy's strategic-missile-firing submarines. A review board consisting of members of the intelligence community and submarine school instructors exhaustively test all target simulations prior to their release to the fleet to ensure real world fidelity. This requirement applies equally to either shoreside or onboard training systems.

The second interpretation concerns operator/team alertness. Conventional wisdom in the past has precluded the use of target injection systems to determine the degree of alertness of sensor operations. The general concern has been that exposing the inadequacy of an operator by injecting a target without his knowledge would lower morale and lead to probable injection system sabotage. That view is questionable. It is reasonable to believe however, that an operator must have a reasonable probability of winning in any contest or otherwise morale will be adversely affected. Because of the total inadequacy of tools to support operational skills development today, the probability of winning is low. However, on some SSBNs with organic stimulator training capability, the operators have developed enough confidence in their capabilities that on their own initiative they have turned the learning process into a game where they pit their detection and classification skills against one another.

Requirement 7 - Training at All Team Levels. Training all members of the ASW teams includes training extending from sensor operators up to and including the command level. For a specific ship in a specific exercise, the extent of specific command involvement is always a function of the judgement of the Commanding Officer in terms of the specific objectives of the evolution and the needs of the ASW team. However, the training system should permit the Commanding Officer to exercise his tactical judgements and measure the results against exercise criteria as a part of the ship's total preparation for war. For those ASW surface ships being equipped with tactical ASW sensors only recently in the inventory, the capability for the Commanding Officer of these ships to develop and evaluate new interpretive and tactical skills is an urgent necessity.

Conflicting personnel requirements when a ship is in port were cited as a limitation of shoreside training systems when discussing the requirement for frequent training opportunities. These same limitations apply when attempting to train the entire team ashore, especially at the senior team member level.

An organic, onboard training capability with inherent "truth table" features would certainly help in this area. A ship team from Commanding Officer on down could stage ASW engagements as frequently as desired without reliance upon outside services and be free to make all the typical mistakes inherent in the learning process without outside observation and command embarrassment. Once individual ship confidence in team abilities is reached, it is not difficult to envision training operations between pairs of ships using stimulator targets, between ships and aircraft, and eventually among complete ASW Task Units.

Requirement 8 - No Geographic Constraints. Fixed ranges such as AUTEC, BARSTUR and St. Croix impose geographic constraints which not only limit accessibility but constrain training to the environmental conditions at that particular location. Such conditions may not be typical of the broad spectrum of conditions experienced throughout the world. AUTEC is a good illustration where the "bathtub" bathymetry of The Tongue of the Ocean precludes effective use of low frequency active sonar because of very high reverberation interference. Organic trainers do not constrain training operations to a particular area.

Requirement 9 - Consistency Between Training and Operational Equipment. It is obvious that onboard trainers which stimulate operational equipment ensure such consistency.

In summary, the material that I have presented in this paper suggests changes to the manner in which ASW training is conducted in the Navy today. My contention is that manpower and resource constraints, coupled with the nature of the submarine threat, demand that the Navy extract every ounce of capability inherent in our sophisticated ASW systems. Accordingly, training and readiness assessment are critical. Fortunately, technology advances will permit heavier concentration on operator training. However, logical and necessary changes are being impeded by unclear perceptions of our current training systems and the lack of a concise statement of top-level requirements. I have suggested such a statement of requirements and argued that organic, onboard training systems come closest to satisfying them.

I am encouraged that others recognize the importance of organic training approaches as a means of shortening the training pipeline and increasing the effectiveness of personnel utilization. The Enlisted Personnel Individualized Career System (EPICS) is a case in point which is being applied to the NATO Sea Sparrow program. The goal of that effort is to develop skill level III trained personnel at the end of six years while having devoted only 50 weeks to shoreside schooling, including recruit training. If successful, this change will constitute a significant improvement in utilization and resource application.

Underlying all that I have said in stressing the need for reducing the training pipeline and in arguing for support of onboard training, is a fundamental belief that everyone enjoys doing that which he knows he does well. We all learned that lesson early in life in school where the subjects in which we received good grades were normally our favorites. Lack of confidence in one's ability to perform assigned tasks or, what is worse, confusion as to what one's job really is, is self-defeating and a morale depressant. I am convinced that training can be fun, that well-trained Navy personnel enjoy high self-esteem, pride of organization, good morale and, accordingly, will tend to remain in the service. Adopting the suggestions proposed in this paper can help to foster that happy situation.

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Dr. Bradford A. Becken graduated from the U.S. Naval Academy in 1946. He was designated an Engineering Duty Officer (Electronics) in the early 1950s and served continuously from 1953 until retirement from the Navy in 1966 in assignments related to sonar systems development and evaluation. He joined the Submarine Signal Division of Raytheon Company in 1967 as Manager of the Systems Engineering Laboratory and began his current assignment as Manager of Engineering in 1970. He holds additional degrees from the U.S. Navy Postgraduate School (B.S., Engineering Electronics) and University of California at Los Angeles (M.S., Ph.D., Physics, Acoustics).

ONBOARD TRAINING PROGRAM DEVELOPMENT: LESSONS LEARNED

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ABSTRACT

Since 1973, General Physics Corporation has been developing operational training program materials for use on board surface ships, submarines, and aircraft of the United States Navy. These programs have been oriented toward providing an individual ship or squadron the capability to increase its operational performance in a particular warfare area through a series of scenario-based exercises, utilizing the unit's own inherent training assets and capabilities. These programs have been evolutionary and as the programs have matured, many problems have arisen which have complicated program organization, development, Fleet implementation, and overall use of the materials. These problems include: confusion and lack of understanding of the nature of onboard training; lack of documentation for combat systems; conflicting or non-existent operational guidance; limitations of imbedded training modes and systems; inability to keep pace with system upgrades and modifications; difficulties in implementing programs and materials; and difficulties in sustaining interest and use in Fleet units. Each of these problems has been encountered and dealt with, with varying degrees of success. These "lessons learned" and other recommendations are presented for the consideration of others embarking on development of onboard training efforts. Navy policy toward onboard training and funding are discussed and recommendations made. Finally a list of thumbrules for onboard training program and material developers is presented.

INTRODUCTION

In 1973 General Physics Corporation commenced development of methodology and materials to support onboard operational training and individual and team assessment in sonar and fire control/attack center operations aboard U.S. attack submarines. This initial effort, sponsored and directed by Commander, Submarine Force, U.S. Atlantic Fleet, was designed to formalize and standardize onboard combat system training, as well as to provide a submarine commanding officer or his operational commander with a quantitative, objective assessment of the ship's overall operational readiness in combat system operation. The Submarine Sonar and Fire Control Operational Readiness Assessment and Training Program (eventually shortened to Submarine Operational Readiness Assessment and Training (SORAT) Program) was developed in close cooperation with the operating Fleet and addressed operation of current onboard systems using existing tactics and procedures, thus encompassing the day-to-day training requirements of an operating ship. A key feature of the program was the extensive use of existing equipment and imbedded training modes or capabilities of the combat system.

SORAT was mass produced and distributed to all Fleet submarine units (including versions for SS and SSBN) in 1978. About this time the program was adapted to support the rapid conversion of submarines to the digital AN/BQQ-5 Sonar and the MK 117 Fire Control System. Today, the program exists in 13 different versions (tailored to various sonar/fire control suites) and is aboard virtually every U.S. submarine.

The same methodologies developed and refined in the SORAT Program have been adapted in recent years to apply to other warfare areas, ship types, and to commercial applications. Examples are the Operational Readiness Assessment and Training System (ORATS) for Surface ASW (FF 1052, DD 963, and FFG 7 Classes), the Deployable Acoustic Readiness Training System (DARTS) for P-3C Patrol Plane Squadrons, (the Battle Group Readiness Assessment and Training System for AAW (Anti-Air Warfare Commander Self Training and Assessment of Readiness (STAR) Program), the ship-level Anti-Air Warfare Readiness Assessment and Training Program (AAW RATS), operator performance assessment for power plant (nuclear and fossil) control room simulators, and the Readiness Assessment and Training System for Submarines of the Royal Australian Navy (ROORATS). Several other adaptations are currently underway or in the advanced proposal stage, including RATS programs in the areas of Electronic Warfare, Navigation and Piloting, and military and civil disaster preparedness.

Each of these programs has been developed independently and each has presented unique problems to the program and material developers. There are, however, common or "generic" problems and difficulties, normally encountered in every project, that must be addressed. The intent of this paper is, therefore, to describe some of these problems, suggest possible resolutions to these problems, and to then list a number of thumbrules which might be of assistance to others in the development of onboard training and/or assessment programs.

ONBOARD TRAINING

What Is Onboard Training?

Before proceeding farther, it is necessary to define "onboard training" as the term will be used in this paper. Much discussion has centered around onboard training in recent years and there is confusion about what onboard training encompasses. In a general sense, onboard training can be thought of as any type of training conducted on or for a unit outside of the shore-based training environment. This definition would therefore include such training as watchstation training, rate training, lectures, seminars, demonstrations, drills, and on-the-job training (OJT), both formal and informal. When onboard training is viewed by any particular individual, however, the definition evoked usually applies only to a very specific area, usually relating to that individual's somewhat parochial interests. For example, to a Division Officer, the quarterly schedule of lectures for the division may be perceived as the extent of onboard training. To an ILS manager at NAVSEA, onboard training may relate only to the training of maintenance personnel to repair his particular piece of equipment. To the educational specialist at CNET, the term might only apply to the area of OJT. To the type or force commander, hopefully the term would apply to any type of training conducted by the ship to establish and maintain its proficiency in operations, maintenance, and overall readiness. The very general term "onboard training" is used frequently to describe a very specific aspect of this training.

This paper will also apply the term to a very narrowly defined area. Onboard training is therefore defined as "individual or team watchstation training designed to provide operational familiarization or proficiency maintenance in those skills required for proper system employment, using actual equipment, where possible, and simulating the at-sea environment realistically." It should be noted that this rather narrow definition excludes equipment maintenance training and other types of training such as lectures and seminars (although it could be readily expanded to encompass these also). It does, however, closely approximate formal OJT and can be thought of as a supplement to this type of training.

One might wonder why such a narrow and restrictive definition of "onboard training" is used. Not using such a sharply defined term leads to the most formidable problem in development of onboard training programs--namely that a program cannot be all things to all people at all times. In proposing an onboard training program to be administered to a certain group on board a ship (the sonar division, as an example), the developer is faced with a diverse array of individuals with widely varying formal training, at-sea experience, attitudes, rates, and proficiency. In addition, there are a variety of skills an operator should possess in order to properly accomplish his assigned watchstation tasks. The developer must structure his program so as to address these diversities between individuals, as well as the different skill areas.

To present an example, take the sonar division aboard a U.S. nuclear attack submarine. The division as a whole must be proficient at detection, classification, tracking, and specialized operating procedures. Further breakdown includes both passive and active operational skills. Additional subsets of skills would include torpedo detection and tracking, and reporting procedures. The division is split into watchsections, so proficiency is required for several groups, as well as for the Battle Stations organization. Skills must be developed at an individual operator level, as well as for the team. Team skills can be assembled from individual skills only with effective coordination and supervision. Therefore, supervisory training must also be addressed. The entry level of personnel into this division is another consideration. The division chief and experienced supervisors do not require the same training that a seaman or junior petty officer should obtain. At any particular level of experience, materials should offer a variety of situations or levels of difficulty so that experience can be acquired on increasingly more difficult tasks. The list could go on and on with further breakdown into desired or necessary areas of training.

All of this suggests an extremely large, complex, and expensive series of training programs, if all of these considerations are to be addressed. Obviously, such a series of programs would be highly desirable, but the cost of developing such a program (for only one division) would be staggering. The developer is therefore left to determine which areas should be addressed, in what depth, at what level of difficulty, and in what manner (medium and format), all within what is normally a very limited budget. He must then wrestle with the problems of how to introduce the materials, how to promote their use, and how to maintain the currency of the program. Obviously, there will be a wide range of opinions on which, what, and how, both internal to the developing organization, and externally within the client's organization.

Some of these specific problems which develop, and which must be addressed, will be elaborated on in the remainder of this paper. They are broken down into five major areas: 1) developmental problems, 2) implementation problems, 3) usage problems, 4) program maintenance problems, and 5) Navy policy toward onboard training.

PROBLEM AREAS

Developmental Problems

As alluded to before, specification of a program, curriculum, or a framework for future development for onboard training is not an easy task. The traditional Instructional Systems Development (ISD) model lends itself more to the development of a formal school-house course of instruction than to a comprehensive ship-administered training program. Since the combat systems to be addressed are normally already installed in operational units, it is desirable to get training materials in place in a short period of time. Unless much of the front-end analysis has been conducted during system design and development, the developer is faced with the lengthy and time-consuming process of task analysis which must be accomplished before proceeding with training program development. Within time and funding constraints imposed by the client, the developer must also decide which areas should be addressed and to what depth. Obviously, these conflicting requirements can cause many headaches and much consternation on the part of developer and client alike.

Our approach to this problem has been to let the client decide. Since the type or force commander is concerned with the ability of his ships to go to war today (and not three years from now) the emphasis has usually been placed on rapid delivery of training materials, using existing tactical doctrine and operating procedures as the documentation of correct operator procedure or response or as a performance standard. Using this approach, material delivery can occur early in program development while, at the same time, details of the long-term program can be filled in as it progresses. Although not an ideal situation for development of a comprehensive program, it does provide the operational commander with materials addressing current needs, while at the same time developing a framework for addressing future systems and requirements.

Even when the framework has been developed, front-end analysis completed, objectives specified, and media determined, the training specialist who will develop the materials is still faced with a multitude of problems. Within the sphere of operational combat system training, these can be placed into two general categories--lack of documentation and equipment limitations.

Lack of Documentation. Perhaps the most frustrating situation for a training material developer is to not have adequate technical and tactical documentation to support training material development. This situation has arisen for virtually every new combat system delivered to the Navy in the past several years. Besides preliminary operating guidelines (based on how a system should work) and technical manuals (often with many "To Be Supplied" pages), little written documentation is available to assist the developer in creating the materials. Our approach to this problem has been to employ subject matter experts, trained in the field of interest, to generate the training materials. These material developers work closely, and interact frequently, with users and technical experts to verify accuracy of the developed materials. As Fleet experience in operating the system is obtained and as tactical procedures are refined, identified improvements can be readily incorporated into the existing materials.

Conflicting Tactical Doctrine. A problem frequently encountered is that of conflicting documentation for a system. This is sometimes caused by the delay in delivering documentation for a system, or by making a change in one publication and not another. Similar discrepancies often develop because of official or unofficial differences between Pacific and Atlantic Fleet operating environments a d tactics. There are two approaches which can be used to alleviate this problem. One is to create materials that are non-specific in the areas of conflict. The other is to develop two versions of the same module, each version reflecting the applicable guidance. Although the latter is the better alternative, it creates administrative problems in dissemination and control of materials. Therefore, the "generic" training material approach is generally used with space allowed for insertion of locally determined amplifying material.

Imbedded Training Capability Problems. One of the cornerstones of all of our programs has been reliance on imbedded training modes and inherent stimulation capabilities of the systems. Based on the premise that the most effective operational training should be conducted on an operator's own equipment in realistic surroundings, built-in training modes are used whenever possible. Although many of these training modes provide excellent high fidelity stimulation, virtually all are somewhat limited and their capability must be supplemented to provide additional realism and effective training. The first characteristic weakness observed in virtually all imbedded systems is that they have been designed solely for stimulation of that particular piece of equipment and no others. For example, the built-in training mode of the MK 117 Fire Control System provides a training capability for Weapon Control Console (WCC) operators, especially in the area of Target Motion Analysis. This mode is adequate for training individual WCC operators but has severe shortcomings if Attack Team training is desired. It is not designed to drive plotters or bearing repeaters and so the Plotting Team is effectively excluded from this team training unless some artifice is used to include realistic sensor inputs. Likewise, the imbedded training mode of the AN/BQQ-5 Sonar System provides an unsatisifactory presentation and a small variety of contacts and must somehow be supplemented or substituted for. In both of these situations, solutions to the problems have been developed which have not significantly detracted from realism. Concurrent operation of the sonar and fire control systems has presented considerable problems, however. Due to the many artificialities required by simultaneous operation for training, the number of personnel required to administer a combined team training exercise approaches the number of exercise participants or trainees and is thus normally impractical to conduct. Designers of future systems should consider the need for complete combat system team training capability (including operation in back-up or casualty modes) in designing imbedded training functions for these systems.

Another deficiency frequently observed with imbedded training functions is the shortcomings, or total lack, of operational checks and preventive maintenance covering these modes and equipment. This is particularly true of some of the older analog, mechanical systems. One prime example is the Own Ship Motion Simulator (OSMOS) used to provide own ship course and speed inputs to fire control and plotting equipment aboard FF 1052 Class ships. On virtually every ship on which the ORATS program was demonstrated the

OSMOS either did not operate at all, or provided only partial or improper input to the equipment. In all cases, this deficiency was unknown to ship's personnel because there was no periodic preventive maintenance to check out the system and testing of the unit was not adequate during new construction or overhaul. To solve this type of problem, it has often been necessary to develop special testing and alignment procedures as adjuncts to training materials for this equipment. These are conducted periodically by the ship to verify proper operation and identify potential faults or problems.

The long term solution to all of these problems is, of course, to build a comprehensive training stimulation and management capability into each new combat system. This process should ideally commence on Day 1 of system specification, and be carried through full scale development with the same priority and emphasis as with any other part of the combat system. Recent events in procurement of systems such as the AN/SQQ-89 and the SUBACS have shown encouraging signs that the Navy is moving in this direction.

System Upgrading and Improvement Problems. A constant thorn in the side of training material developers (for which there is currently no good solution) is the seemingly endless series of changes and updates to current combat systems. Take for example the AN/BQQ-5 Sonar System. There are three versions of the system (Baseline, A, and B) installed on submarines today with another scheduled for introduction in the next few years (C). For a developer to produce materials for each is, in itself, a formidable task. Add to this a series of updates (FY-79 update, FY-81 update, etc.), each of which modifies operation of the system. Now the developer must choose between creating training materials so general that they can cover all systems or creating several different versions of each module detailed to address all configurations. With the large number of systems in use, the administrative burden of keeping track of who has what is staggering.

A variation of this same problem recently occurred when a software change to a combat system rendered over 50% of the training materials in the Fleet addressing that system obsolete. At present the only solution to this problem is to withdraw the obsolete materials from circulation and gradually replace them as time and funding permit.

Implementation Problems

When the training materials have been produced, the overall job is only partially complete. The materials must be introduced, demonstrated, and integrated into a ship's existing training program. A well conceived, timely, and efficient implementation plan is essential to the long-term success of any training program or training materials which will be used by operating forces on board ship.

A well-conceived plan is one which will provide exposure of the program to the largest number of units, provide a comprehensive view of the overall program and specific examples of materials, place the least possible administrative burden on the ship, and convince personnel on the ship that the program can, in fact, help them upgrade and maintain their operational readiness.

In this area, advanced planning is the key element to avoid problems. This planning should be done with the cognizant squadron or force representatives in order to facilitate scheduling of individual units. A detailed agenda of each proposed ship visit should be prepared and submitted to the squadron for review and comment. Examples of items which should be covered in the implementation visit include briefings on program purpose, objectives, mechanics, and methods structured toward a particular audience (e.g., Wardroom, Sonar Division, Section Tracking Parties). Then, representative examples of the training materials contained in the program should be demonstrated. As an example, during SORAT Program implementation visits, individual as well as team sonar and attack team exercises are conducted on each ship. Finally, time should be set aside to assist division officers and leading petty officers by suggesting methods for integration of the training materials into existing training plans and qualification processes.

A key factor of this advanced planning is selection of personnel to conduct the implementation. The single most important attribute of these personnel is credibility, followed closely by the ability to communicate with all echelons of the Navy structure, from junior enlisted to flag officer. The implementer's credibility includes knowing the program, knowing the audience, and being able to relate the conditions and environment of the ship to his own experience. The ability to communicate effectively is, in fact, a major part of the individual's credibility, and implies the ability to discuss the specific aspects of the program in layman's terms, not those of academia or the educational community.

The second element of a successful implementation is timing. Coming aboard a ship two days before a major inspection or during loadout for a deployment can totally destroy any positive attitude toward a program. There is no single best time to plan for implementation, but ideally the period shortly after a major overhaul is the best. Personnel are normally anxious to go to sea, and desire to hone their previously established operating skills which have been dulled by the long in port period. Obviously, if implementation is conducted on a squadron basis, not all ships will be at the same point in the overhaul cycle. But in establishing a long term, individualized program, this post-overhaul period is ideal for introducing a program.

The third element in successful implementation is efficiency. This depends to a large extent on the advanced planning which has been done. The flexibility of implementation team personnel is also a major factor. The ability to respond professionally and knowledgably to a particular problem reflects well on the program as a whole. For example, suppose a particular demonstration scheduled in the agenda cannot be accomplished because the equipment is down for maintenance. The team should be able to suggest and conduct alternate demonstrations not requiring use of that piece of equipment. The crew's time is valuable and any real or perceived waste of that time will detract from acceptance of the program or materials.

The final element of success is to get squadron personnel to assist, or at least be present, for each implementation visit. In addition to adding an air of squadron interest and participation to the implementation, it also serves to indoctrinate and train on-site program facilitators who will be able to provide implementation visits on their own to units not present when the original implementation is conducted.

Usage Problems

It is not uncommon to hear from a training material or program developer the plaintive cry, "I pour my heart and soul into developing the best possible training materials, show the Fleet how to use them, and convince them that they can increase their readiness by using the materials, and then the Fleet doesn't use them! Why?" The answer is simple--lack of time. Anyone who has served on a fast attack submarine knows that the acronym, SSN, does frequently stand for "Saturdays, Sundays, and Nights." The same holds true for virtually every other platform in the Navy. With heavy preventive and corrective maintenance schedules, shortages in manning, hectic operating schedules, and a host of other requirements, both inport and at sea, the time available for onboard training is extremely limited. On a list of priorities for an upkeep, training would probably come last, and would be the first item to slip off the list as the time to get underway approaches. Therefore, how can onboard training program usage be initiated and maintained?

Part of the responsibility for this lies, of course, directly on the shoulders of the Navy. Emphasis on the importance of training and perhaps even a mandate for its use will provide part of the answer. However, it is also the responsibility of the material and program developer to assist in this by producing a product which is responsive to shipboard application and use. In our experience, several factors most directly affect shipboard attitudes and usage. The most significant of these are realism, administrative burden, and user feedback.

A trainee will often make a comment such as, "This contact doesn't sound (or look) like the real ones on my system." Because of this discrepancy between what is contained in the training material and what the trainee perceives as the real world, he will often "turn off" to the material, regardless of the desired objective of the material or of its inherent importance or training value. Therefore, care must be taken in constructing any operational training material to ensure that it accurately reflects the environment, contacts, procedures, tactics, and situations encountered in actual operation. This is normally best assured by a rigid and comprehensive validation process which consists of technical (does this exercise proceed as it was designed to?) and content (does it meet its stated learning objectives?) validations in conjunction with Navy subject matter experts.

The second important factor is the administrative burden placed on the ship by implementing or integrating a formal onboard training program. It is our firm belief that any program imposed as an additional training requirement is instantly doomed to failure. Rather, the program should be developed to: replace some aspect of presently required training (conducting an onboard attack team exercise in lieu of one attack trainer session); enhance training within an existing framework (a sonar team classification exercise in lieu of a divisional lecture on classification); support the watchstation qualification process (materials designed to prepare a trainee for performance of a practical factor); support ship qualification or advancement in rate; and support at-sea watchsection training without interrupting normal routine.

User feedback is another important aspect. If personnel in the Fleet are solicited for input and comments concerning the program or its materials, a much greater appreciation of its existence can be developed. In fact, incorporating Fleet comments and recommendations into the program can result in a "pride of authorship" situation which also promotes wider usage. Perhaps many would brush aside this factor as simply "stroking the egos" of the users, but in the long run it provides a program responsive to current Fleet needs, in a form and package suitable for (and conducive to) use on board. We strongly recommended that any program designed for use on board include input from the user and provide a viable feedback process to make this happen.

Navy Policy Toward Onboard Training

Despite a stated strong commitment to onboard training by the Deputy Chiefs of Naval Operations (Submarine and Surface Warfare), as yet there exists no Navy-wide or ship-type-wide policy addressing it. Several factors are responsible for this. First is the relative newness of the concept itself--that is, training of at-sea forces using outside assets. Since the establishment of the U.S. Navy, the concept that the Commanding Officer is ultimately responsible for the training and readiness of his ship has been a guiding principle. This is no less true today than it was two hundred years ago. But now, the systems at the disposal of the CO are much more complex, the enemy is equipped with comparable systems, the administrative burdens are increased dramatically, requiring the CO to have outside assistance. This assistance, in the form of onboard training materials and programs, must be coordinated and well planned, and policy concerning this should be determined at the highest levels of the Navy. This plan must consider integration of existing formal school training, shore-based operational training, refresher training, and present normal operational training exercises. Several type commanders have made admirable headway in developing such coordinated programs. Most notable are COMSUBPAC's PORT and STBD program and COMSURFPAC's Combat System Training Architecture program which define cyclical training requirements for ships between overhauls. However, a Navy-wide program or policy should be estabished to ensure conformity and standardization.

A second problem concerning onboard training policy is that there is no one single office within the Navy which is tasked to control or coordinate the area of onboard training. Currently there is much confusion about who has cognizance over what aspect of onboard training (and trainers for that matter). Warfare commanders, type commanders, NAVSEA, NAVAIR, NAVELEX, NTEC, CNET, and other Navy training commands--all of these have somewhat different perceptions of what onboard training is and should be, and who is responsible for each aspect. A high level determination of which organizations should exercise cognizance over the various aspects of onboard training should be made as part of an overall policy statement.

The final policy-related problem to be discussed, one which is dear to the heart of every contractor engaged in onboard training program support, is that of funding. Funding wise, onboard training programs are true orphans. Presently, most funds earmarked for onboard training are O&M, N which are very short-lived and cut into the operating budgets of the type commanders. In this era of major shipbuilding and weapons procurement, stringent oversight and budgetary restraint, the first funds to be cut will be from O&M, N monies. Therefore, type commanders are faced with the unenviable choice of keeping their ships at sea by funding needed maintenance, or providing additional training to upgrade and maintain personnel readiness.

The perishability of this funding (with its one-year lifetime) presents problems to the Navy sponsor, as well as the contractor, in setting up and maintaining a long-term, systematic program. As part of a desired Navy-wide policy, funding for development of long-term onboard training programs should be addressed, just as life cycle supply support is addressed in procurement of a new combat system.

SUMMARY

Onboard training, particularly onboard training which is supported long-term and is part of an overall Navy-wide approach to maintaining a high state of operational readiness, is a concept whose time has come. Although development of onboard training programs has been, and will continue to be, a challenging and often frustrating task, the ultimate rewards and satisfaction can be great--both for the Navy and the training material developer. It has been one intent of this paper to show that all of these past, present, and future programs are evolutionary, solely because of the nature of the beast. And they will continue to change and improve as more experience is gained in this area.

In conclusion, a list of thumbrules for the program or material developer is provided which, hopefully, can be of use to others embarking on onboard training program development.

1. Don't underestimate the abilities of the audience. Today's sailor or soldier is intelligent, alert, and highly trainable.

2. Don't anticipate the requirements of the user. Get down to the waterfront and find out for yourself.

3. Enlist the participation and input of <u>operating</u> Navy personnel whenever possible.

4. Don't bite off more than you can chew. Don't promise a panacea when you are only delivering a Band-Aid.

5. Likewise, don't deliver a body cast when a Band-Aid will do.

6. Remember when you go aboard a ship, that this is the sailor's home and he expects you to treat it as such.

7. Don't be disappointed when someone doesn't think your materials are as good as you do. Someone, somewhere, can always do it better.

8. Know the environment that your materials will be used in (on board the ship) and develop them so that they can be used there.

ABOUT THE AUTHOR

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USER GUIDELINES FOR DECK OFFICER TRAINING SYSTEMS

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ABSTRACT

The ship bridge/shiphandling simulator, with a large visual scene, is a relatively new development for the training of deck officers. The U.S. Coast Guard and U.S. Maritime Administration have jointly sponsored the Training and Licensing Project to investigate the role of the ship bridge/shiphandling simulator in the training and licensing of deck officers. A major product stemming from this multi-year research is a set of guidelines for the development of deck officer training systems. The guidelines address the simulator/training device, the training program, and the instructor. The guidelines are intended for use by operational organizations to assist in determining the adequacy of available simulator-based training programs to fit their specific needs, and to assist in specifying training systems for procurement. The guidelines have a generic structure to address all levels of deck officer training. The specific content of the guidelines was initially developed to address masters-level training. The initial direct application of the guidelines, however, was for the design of a simulator for Maritime Academy cadet training. Each of these are briefly discussed.

INTRODUCTION

National and International concern regarding the safety of merchant vessels, crews, and cargoes has increased substantially in recent years. This increasing concern is occurring with the public, regulatory agencies, shipping companies and the general body of mariners themselves. As the productivity of shipping has increased over the years, so have the risks associated with shipping, the difficulty of operations and the requisite level of mariner skill required, and also the potential damage and cost of accidents. Whereas the maximum size of ships afloat 50 years ago was 6000 dead weight tons (dwt), the larger ships float today exceed 500,000 dwt.(21) The allowable margin of error in maneuvering a vessel has generally decreased as the vessel size increased; the amount of hazardous cargo carried has generally increased, particularly in the larger vessels (e.g., crude oil, liquified natural gas). As might be expected, the annual tonnage loss has also steadily increased. Whereas in 1962 about 125 ships were lost, representing about 525,000 gross tons, in 1977 slightly more than 200 ships were lost representing more than 1,200,000 gross tons.(15) These increases represent substantial financial loss, and often catastrophic loss of life and damage to the environment. Several investigations into the cause of maritime accidents have indicated that as much as 80 percent of the contributory causes may be traceable to human performance.(2),(13),(22) In addition, several other investigations have sought to delineate the specific aspects of human performance, as well as other factors, that are prime contributors to maritime accidents.(18),(16) As a result of these factors, considerable emphasis has been placed by all segments of the maritime industry on the improvement of mariner proficiency including better human factors design of the man-ship interface and improved training programs.

The ship bridge/shiphandling simulator is a tool that has recently become available to assist in the improvement of deck officer training. The first shiphandling simulator, the Marine Research and Training Center of Port Revel near Grenoble, France, was built in 1967. It consists of an eight acre lake with 1:25 scale model ships in which two trainees sit, and maneuver around the lake. The first electronic ship bridge/shiphandling simulator became operational in 1968 at the Institute TNO for Mechanical Constructions in the Netherlands. The predominant difficulty in the development of the ship bridge/shiphandling simulator has been, and still is, the visual scene technology. A large visual scene, of up to 360 degrees horizontal field of view is necessary in this type of a simulator. A variety of approaches have been used to achieve a visual scene, with virtually all simulators substantially differing in the technology used until the present time. More recently, computer generated imagery has emerged (i.e., within the past 5 years) as a stable technology for this type of visual scene simulation. Several simulators are currently operational with computer generated imagery, while several others are in the planning and construction stages. Hence, the recent technological advances in simulation have resulted in a growing use and acceptance of the ship bridge/shiphandling simulator as a viable means for improving the proficiency of deck officers. The growing acceptance of this approach to training is underscored by recent national and international actions:

- The U.S. Port and Tanker Safety Act of 1978 calls for the upgrading of deck officer skills, while specifically calling for the establishment of standards relating to "qualification for licenses by use of simulators for the practice or demonstration of marine oriented skills".[19]

- The U.S. Coast Guard allowance of successful completion of a simulator-based training program to satisfy 40 percent of the pilot endorsement requirements for the Port of Valdez, Alaska.

- The IMCO Convention on the Standards of Training and Watchkeeping [14] recognizes simulator-based training as a means of acquiring shiphandling skill for transitioning to a vessel with unfamiliar handling characteristics.

- Europort Pilots have been undergoing simulator-based training periodically as a self-imposed requirement for practicing and improving their shiphandling skills.

- Shipping companies have increasingly sought the use of simulator-based training programs for their deck officers. Labor unions, likewise, have recognized the potential of simulator-based training and have acquired facilities to provide such training, as well as encouraged their members to utilize the facilities of training schools.

Training and Licensing Project

As a result of the growing concern about maritime safety and productivity, the emergence of acceptable ship bridge/shiphandling simulation technology, and the growing interest in simulator-based training for deck officers, the U.S. Coast Guard and U.S. Maritime Administration embarked on a joint investigation of the role of the ship bridge/shiphandling simulator in the deck officers training and licensing process. This multi year project (i.e., Training and Licensing Project) was conducted by the Computer Aided Operations Research Facility (CAORF) of the National Maritime Research Center. The project encompassed several phases which addressed simulator design and application issues, as well as the range of deck officer licensing categories.

The problems in the maritime industry relating to the design and use of simulator-based training are similar to those encountered in other industries which draw on the use of complex electronic simulators. They are (1) the cost/effective application of ship bridge/shiphandling simulator for the training of deck officers (e.g., training objectives that can be effectively met by such training); (2) the cost/effective design characteristics of the simulator/training device and other parts of the training system (i.e., training program and instructor), and (3) the effective design characteristics of the training system with regard to obtaining some type of deck officer license credit. The Training and Licensing Project addressed these issues in a systematic manner, basing its investigation on the general systems approach to training (e.g., Instructional Systems Development (ISD).[1]

The initial phase of the Training and Licensing Project [12] (1) developed the methodology to be used throughout the duration of the investigation, based on tailoring the systems approach to the particular needs of the Maritime Industry; (2) developed an extensive information base addressing deck officer behavior and training technology; and (3) identified research needs to adequately address the design and use of the ship bridge/shiphandling simulator in training.

The second phase of the program conducted empirical research on the CAORF ship bridge/shiphandling simulator to investigate (1) the training effectiveness differences of alternative training system characteristic levels of fidelity (e.g., color versus black and white visual scene; compressed versus distributed practice; instructor differences); and (2) the training effectiveness of simulator-based training for master's level deck officer and for maritime academy cadets. A variety of findings were forthcoming from these empirical investigations.[9],[10] These investigations address the application of simulator-based training, and the cost/effective design characteristics for achieving an effective training process.

The third phase of the program was devoted to (1) the development of guidelines for master's level deck officer training systems, and (2) the design of a simulator/training device for cadet training drawing upon the extensive research conducted during the earlier two phases. Initially, the third phase was going to develop criteria for evaluating and approving simulator-based training facilities as meeting some minimum standards for licensing purposes. If credit were to be given towards some licensing requirement, the school would have to be certified by a regulatory body.[3] The Training and Licensing Project was to have developed training system acceptance criteria by which this evaluation could be accomplished. Since it was not feasible to make simulator-based training a part of the licensing structure at this time, it was decided to develop User Guidelines for the design and use of ship bridge/shiphandling trainers rather than criteria for their evaluation.

The Guidelines for Deck Officer Training Systems [5] are the result of the earlier phases of research on the Training and Licensing Project. They are intended as a user's guide to the design and use of the ship bridge/shiphandling simulator for training deck officers. In particular, the guidelines provide an overall structure for the design of the training system characteristics keyed to deck officer tasks. The guidelines were initially developed for the training of senior mariners (i.e., master's level deck officers), hence the specific details of guidance provided address the master's level. The guidelines identify deck officer tasks, indicate those tasks requiring training emphasis via analysis of the accident literature, identify critical simulator and training program characteristics, provide guidance regarding the use of three distinct levels of quality/fidelity for each characteristic in consonance with the objectives and conditions of training and recommend a set of minimum level simulator and training program specifications for each of five major training modules. The training system elements addressed include the simulator/training device, training assistance technology to be included as part of the simulator/training device (e.g., feedback displays), training program characteristics (e.g., instructors guide), and instructor characteristics. The guide is intended for use by operational organizations to assist in determining the adequacy of available simulator-based training programs to fit their specific needs, and to assist in specifving training systems for procurement.

TRAINING SYSTEM GUIDELINES

The guidelines for deck officer training systems were designed around a general purpose structure, tailored to the needs and resouces of the maritime industry, with specific content directed at the master-level mariner. The structure of the guidelines were based, as noted earlier, on the general systems approach to training which has been utilized in a variety of forms in the training/simulation industry over the past 20 years. Whereas the specific content of the guidelines addresses the masters-level mariner they can also be applied to the design and selection of training systems for other levels of deck officers. The example given later in this paper addresses the application of these guidelines and the actual design of a simulator-based training system for maritime academy cadets.

The use of ship bridge/shiphandling simulators is growing rapidly, as noted above. Each of the approximately two dozen simulators in use world-wide differ substantially from every other simulator/training device. These differences generally focus on the visual scene, although they also pertain to other major characteristics such as the hydrodynamic equations of motion. As a result, each simulator has substantially different capabilities and limitations. Furthermore, simulation technology is improving rapidly making available new approaches to the design of simulator/training device characteristics. The technology advances directly relate to the cost/effectiveness of simulator-based training. Although the maritime industry has had experience with simulator/training devices (i.e., part-task radar training devices), they have had little experience with the sophisticated and complex ship bridge/shiphandling simulators from a design and applications standpoint. Hence, the guidelines have been developed to be used by shipping companies, labor organizations, and mariners in general. The guidelines are not specifically intended for use by the simulator manufacturer/electrical engineer in the sense of providing detailed engineering design characteristics (e.g., number of pixels on the visual screen). Rather, they are aimed at the operational level mariner. They are intended to give him guidance with regard to the characteristics that are relevant on the simulator, their need and application in training, and their expected capabilities and limitations. The guidelines translate operational functional requirements into their associated training system characteristics.

The guidelines user (e.g., shipping company training specialist) would use the information in the guidelines to (1) specifically detail his particular training needs, (2) compare his training needs with the capabilities and limitations of each alternative fidelity-quality level for each training system characteristic, and (3) arrive at a conclusion to specify the minimum or desired level required for each training system characteristic to achieve his particular training needs. This final step would result in a set of training system functional design characteristics with which he could evaluate different commercially available training system facilities for purchasing training time, or develop a specification for perspective bidders to develop an appropriate training system.

The three major steps of the guidelines, which correlate with specific sections of the report, are briefly discussed below.

Training Needs (Section #1)

Training needs are typically identified in the form of operator tasks or training objectives that are to be achieved via the training program. These training objectives or tasks must be feasibly achievable via simulator-based training on a cost/effective basis. A specific set of masters-level deck officer training objectives (i.e., called Specific Functional Objectives) that are cost/effectively achievable via simulator-based training were developed in the Phase 1 Investigation of the Training and Licensing Project.[12] Many of the training objectives in this set can also be achievable via other training media (e.g., at-sea training). The guidelines user, therefore, would use this set of training objectives as the starting point for determining his specific subset of training objectives. Of course, he may also add additional training objectives not in the developed set.

To select the specific subset of training objectives that constitute the goals of a particular course, specific criteria must be employed. The license level of the trainees (e.g., master) is one such criterion. A second criterion is the type of training that will be provided, such as (1) upgrading to a higher license level (e.g., first mate upgrading to master); (2) training to handle a vessel substantially different than those in which the trainee has experience (e.g., transitioning from a 30,000 dwt tanker to a 170,000 dwt tanker); and (3) refresher training (e.g., periodic retraining in emergency shiphandling). Usually, one of these three training types is specifically addressed in each training program. A third criterion is the relative importance of improving certain skills (i.e., addressing particular training objectives). The guidelines address these criteria in the form of recommendations based on analysis of marine accidents.

The first two of the above criteria are relatively straight-forward, and readily specified by the guideline user. To provide guidance with regard to the third criterion (i.e., training areas keyed to accident causal factors) seven major accident analyses were compiled to determine the major areas to receive training emphasis. Six major training areas resulted:

1. Navigation management training
   - Pilot/master relationship
   - Bridge procedures (e.g., established navigation position, monitor other vessel)
   - Bridge organization (e.g., vessel manning)

2. Ship-to-ship communications training

3. Shiphandling training (e.g., safe speed, compensating for external forces)

4. Emergency shiphandling training (e.g., power failure)

5. Rules-of-the-road training

6. Restricted waters navigation training

If the regulatory bodies were to give credit toward a license for simulator-based training, such credit should be provided for training that addresses the above areas (i.e., accident relevant deck officer skills), rather than other possible areas of training (e.g., ship productivity). The deck officer skills that should be addressed under each of the six areas were identified, to provide a greater depth of guidance. For example, the following is one of several sets of skills that should be addressed under Shiphandling Training:

"The trainee should demonstrate proficiency in handling a specific type and size of vessel to stop or slow the vessel effectively under various conditions of wind, current, and water depth when:

- approaching a single point mooring buoy
- approaching a dock/pier
- maneuvering to bring up a pilot
- maneuvering to bring up tugs
- anchoring"

Additional detail regarding other skills was provided under the Shiphandling Training area, as well as under the other five areas. Guidance regarding the integration of the above three criteria is provided in Table 1. This

TABLE 1. HIGHLY IMPORTANT TRAINING AREAS ACCORDING TO TYPES OF TRAINING AND CHIEF MATE/MASTER LEVEL LICENSE

TRAINING AREAS	UP GRADING		TRANSITION		REFRESHER	
	CHIEF MATE	MASTER	CHIEF MATE	MASTER	CHIEF MATE	MASTER
NAVIGATION MANAGEMENT		H				H
COMMUNICATIONS	H	H			H	H
SHIPHANDLING	H	H	H	H	H	H
EMERGENCY SHIPHANDLING	H	H	H	H	H	H
RULES OF THE ROAD						H
NAVIGATION						H

H HIGH IMPORTANCE

table recommends those training areas (i.e., "H" equals high priority) that should be addressed according to the type of training (e.g., transition, refresher, upgrading) and the trainee level (e.g., masters-level). This table, therefore, recommends those training areas that should be addressed with regard to the guideline user supplied criteria (i.e., training type and trainee level). The guideline user would identify his training needs by entering the table with the training type and trainee level criteria, and receive guidance with regard to the training areas that should be addressed. For example, transition training programs at the master's level should address Shiphandling (#3) and Emergency Shiphandling (#4) training areas.

The guidelines themselves [5] provide more detailed information regarding each of the six training areas. The guideline user may also have other criteria to further delineate his training needs. In the example provided later addressing cadet training a set of training objectives were developed to identify those specific training needs that should be achievable via simulator-based training, at-sea training, and classroom training. This first step of the guidelines, therefore, provides the methodology for establishing training needs and also specific criterion information in that regard.

Training System Characteristics (Section #2)

The guidelines address the design and use of a deck officer shiphandling training system, rather than merely a training device or simulator. The major parts of the training system are:

1. Training device -- typically viewed as the ship bridge/shiphandling simulator; but actually should consist of more than just the simulator, including feedback displays, performance indicators, and so on.

2. Training program -- consisting of the detailed training course curricula, support materials (e.g., visual slides), instructors guide, and so on.

3. Instructor.

Traditionally, the training system emphasis has been on the design of the simulator (i.e., the real-world fidelity characteristics of the training device). Recent research has indicated that the instructor is, perhaps, the most important element of the training system.[9] This finding indicates that the non-simulator aspects of the training system are at least as important as the simulator with regard to achieving an effective training process. The training program and its associated support materials represent major tools used by the instructor in achieving an effective training process.

Other research particularly addressing the training device has indicated that "the training device is more than a simulator".[7] Rather, the training device should consist of both simulation and training subsystems. The simulation subsystem consists of those fidelity characteristics attempting to duplicate real-world functioning. The training subsystem, on the other hand, provides a variety of capabilities to assist the instructor in conducting an effective training process. A variety of instructor support capabilities (e.g., automatic performance monitoring; generation of graphical feedback displays to illustrate aspects of performance) are readily and cheaply available on computer-based simulator/training devices. Research has indicated that these capabilities can have a substantial impact on the effectiveness of simulator-based training.[8] Hence, the cost/effective training device should include a simulation subsystem and a training subsystem, both of which should be tailored to the specific aspects of the training needs and the training situation on a cost/effectiveness basis.

Specific guidance is provided for each of the major parts of the training system, including the simulation and training subsystems of the training device. Critical characteristics associated with each of the major parts of a simulator-based training system have been identified (Table 2). The major section of the guidelines addresses each of these critical characteristics, as follows:

- An overview of each critical characteristic is provided, addressing available alternative technologies for its achievement, and pertinent issues and considerations regarding each characteristic.

- Three levels of fidelity/quality have been established for each critical characteristic. Specific guidance information is provided regarding the capabilities and limitations of each level as pertains to the behaviors, conditions, and performance standards associated with training objectives.

The information provided in the guidelines was derived from (1) empirical research findings eminating from earlier phases of the Training and Licensing Research Program, as well as other independent research efforts; and (2) evaluations and judgements by operational and training experts. Some relative costing information is also included where pertinent. Specific cost information in a set guidelines such as these, however, would likely be inaccurate due to the rapidly changing technology of the simulation field. Rather, at the time of applying the guidelines specific costing information should be developed (see below with regard to the cadet training device design application).

A specific example of the format and content of the guidelines for one critical characteristic (i.e., simulator design characteristic, visual scene, horizontal field of view) is provided in Appendix A. This example is illustrative of the level of detail and type of information

TABLE 2. CRITICAL SIMULATOR-BASED TRAININGSYSTEM CHARACTERISTICS

Simulator Design (Critical Characteristics)

Visual Scene
- Geographic Area
- Horizontal Field of View
- Vertical Field of View
- Time of Day
- Color Visual Scene
- Visual Scene Quality

Radar Presentation
Bridge Configuration
Ownship Characteristics and Dynamics
Exercise Control
Traffic Vessel Control
Training Assistance Technology
Availability

Training Program Structure (Critical Characteristics)

Skill Levels After Training
Skill Levels Prior to Training
Training Objectives
Training Techniques
- Knowledge of requirements
- Positive guidance
- Adaptive training
- Post problem critique

Instructor's Guide
Classroom Support Material
Simulator/Classroom Mix
Training Program Duration
Class Size
Scenario Design
Number of Scenarios
Stress
Overlearning

Instructor Qualifications (Critical Characteristics)

Mariner Credentials
Instructor Credentials
Subject Knowledge
Instructor Skills
Instructor Attitude
Student Rapport
Instructor Evaluation

contained in this section of the guidelines. Information similar to that in Appendix A is provided for the other critical design characteristics of the simulator, the training program structure, and the instructor qualifications. As might be expected, relatively little detailed objective information is available from the research literature regarding any of the above training system parts. The Training and Licensing Project (9) concluded that the empirical data resulting from the research on CAORF supports a highly structured subjective approach to the design of the training system. This, in essence, supports the approach taken in these design guidelines, combining available objective data as baseline information, and using highly structured subjective evaluations to address the remaining necessary characteristics. Following this approach, considerable information has been developed in the guidelines regarding the simulator and the training program. Relatively little information, however, is provided in the guidelines for the instructor characteristics. This is due to a general lack of investigation regarding the qualities of an effective instructor.

Recommendations For Master-Level Mariners (Section #3)

The generic part of the guidelines consists of the above two sections. The generic structure is complimented by specific information content addressing the masters-level deck officer. The third and final section of the guidelines is not generic, as is the above two sections, but rather provides recommendations specific to the masters-level deck officer. The guideline user needs are thus integrated with the training system characteristics guidance information to achieve a specific set of recommendations. The recommendations address the six training areas and the masters-level license; they do not, however, address the three training types. They could, of course, be further refined to address each of the training types (e.g., transition training).

The recommendations provide a "Recommended Level" and a "Minimum Level" associated with each of the critical training system characteristics, for each of the six training areas. Table 3 lists the Recommended and Minimum levels for the training system characteristics associated with the Emergency Shiphandling training area. If the guideline user was going to purchase a simulator-based training program for emergency shiphandling training of master-level deck officers, he would go to this table to determine the requisite levels of critical training system characteristics. Several examples from Table 3 are:

- The recommended simulator visual scene horizontal field of view should be greater than 240 degrees; the minimum acceptable level would be 120 degrees to 240 degrees (note, these refer to specific categories addressed in Section #2 of the guidelines).

- The training program duration is recommended as 3 days; this is also considered to be the minimum training program duration.

- The training program class size is recommended as 3 students or less; however, up to 6 students would be acceptable; greater than 6 students in a class would be unacceptable.

- It is recommended that the instructor possess a pilot's license or pilot endorsement; he should, as a minimum, have a masters license.

TABLE 3. SUMMARY OF RECOMMENDED TRAINING SYSTEM GUIDELINES FOR EMERGENCY SHIPHANDLING

CRITICAL TRAINING SYSTEM CHARACTERISTICS	RECOMMENDED LEVEL	MINIMUM LEVEL
Simulator		
Visual Scene		
Geographic area	III: Restricted water	II: Coastal
Horizontal FOV	III: Greater than 240°	II: 120° to 240°
Vertical FOV	III: Greater than ±15°	II: ±10° to ±15°
Time of day	III: Day/night	I: Day only
Color visual scene	II: Multi-color	I: Black and white
Radar Presentation	II: Low fidelity radar	I: No radar
Bridge Configuration	II: Full bridge	I: Reduced bridge
Ownship Characteristics	III: Special effects	II: Shallow water
Exercise Control	III: Instructor exercise control	I: Exercise selection
Traffic Vessel Control	III: Independently maneuverable	I: Canned traffic
Training Assistance Technology	II: Feedback display	NONE
Availability	II: High availability	II: High availability
Training Program		
Skill Level After Training	II: Direct skill improvement	II: Direct skill improvement
Skill Level Before Training	III: Simulator diagnostic evaluation	I: No diagnostic evaluation
Training Objectives	III: Highly structured	II: Moderately structured
Training Techniques		
Knowledge of requirements	Various techniques	Various techniques
Positive guidance	Various techniques	Various techniques
Adaptive training	II: Group adaptive training	I: No adaptive training
Post problem critique	III: Complete and immediate feedback	II: Immediate feedback
Instructor's Guide	III: Documented instructor's guide	II: Undocumented instructor's guide
Classroom Support Material	III: Advanced support media	I: Basic support material
Simulator/Classroom Mix	III: Prebriefing/simulator/postbriefing mix	II: Simulator/postbriefing mix
Training Program Duration	II: 3 Days (24 hours)	II: 3 Days (24 hours)
Class Size	I: 3 or less students	II: 6 or less students
Scenario Design	Various levels	Various levels
Number of Scenarios	III: Desired practice	II: Moderate practice
Stress	III: Progressive stress	III: Progressive stress
Overlearning	II: Desired overlearning	I: No overlearning
Instructor		
Mariner Credentials	III: Pilot's license/endorsement	II: Master license
Instructor Credentials	III: Instructor course	I: Educational certificate
Subject Knowledge	II: Exhaustive knowledge	I: Satisfactory knowledge
Instructor Skills	III: Outstanding	I: Marginal
Instructor Attitude	III: Enthusiastic	I: Reserved
Student Rapport	II: Respected	I: Competent
Instructor Evaluation	I: Continuing II: Diagnostic	I: Continuing II: Diagnostic

The recommended and minimum levels associated with each of the critical training system characteristics are the titles pertaining to the alternative levels of fidelity/quality for each of the respective characteristics (Section #2). Note that the general ranking of the alternative levels are also indicated (i.e., I lowest - III highest). The guideline user would obviously refer to Section #2 when using this table of recommendations.

Guideline Summary

The guidelines for deck officer training systems has three major parts: (1) training needs, (2) training system characteristics, and (3) pecific recommendations for masters-level deck officers. The structure of the guidelines, represented by the first two sections, is generic and is applicable to various levels of deck officers, types of training, and training objectives. The content of these sections of the guidelines are specific to the masters-level deck officer, although they do generally apply to other levels of deck officers. The third section of the guidelines represents the integration of the first two sections pertaining specifically to the masters-level deck officer; it is hence not generic.

The remainder of this paper discusses an example of the application of these guidelines to the design of a simulator-based training device. The particular training device designed was not for masters-level training, as are the above examples. Rather, it was for cadet-level training. Hence, the general structure of the guidelines was used, although the specific content had to be developed and tailored for the cadet-level training.

APPLICATION OF TRAINING SYSTEM DESIGN GUIDELINES

Background

In 1980 the Maritime Administration, realizing the potential benefits of simulator training within the maritime cadet curriculum, directed CAORF to develop (1) a functional specification for a maritime academy ship bridge/shiphandling simulator and (2) training program recommendations for the proper integration of such simulator training into the maritime academy program. This developmental work was conducted as part of the Training and Licensing Project. It drew heavily on the "Guidelines for Deck Officer Training Systems" and represents the first practical application of the guidelines. It should be noted that simulator-based training is not an unfamiliar training medium for the academies since all have radar simulators and some have cargo handling simulators. However, none of the six academies have a full mission ship bridge/shiphandling simulator, nor do they have experience with the operation of this potentially powerful training device which may be many times as complex as the normal radar simulator.

The approach taken to achieve these objectives was consistent with the overall approach and findings throughout the Training and Licensing Project, which base the design and utilization of a training device on the specific skills to be achieved. The analysis specifically addressed the full-mission ship bridge/shiphandling simulator. Although other training media were considered with regard to achievement of the identified training objectives, the resultant characteristics were determined only for the ship bridge/shiphandling simulator. The specific approach taken involved the following sequential steps:

1. Identification of Maritime Cadet Training Objectives. A listing of specific maritime cadet training objectives were identified, based on third mate watchstanding tasks along with the skill and knowledge requirements for proficiently performing these tasks. It should be noted that these represent the desired skills and knowledge of a new third mate upon graduation from a maritime academy and entry into the merchant marine, for watchstanding tasks only. The training and education provided by the various maritime academies is obviously much broader than those identified for this analysis of ship bridge/shiphandling simulator-based training. The developed training objectives formed the behavioral data base of training needs.

2. Analysis of Maritime Cadet Training Objectives. The identified cadet training objectives were then allocated to various training media available for maritime cadet training (i.e., classroom, small vessel, at-sea training ship, or simulator). Those training objectives which were identified as being achieved best via simulator and were of highest priority were designated as the goals of the simulator-based training system design process.

3. Establishment of Simulator Functional Requirements. Primarily using the information contained in the "Guidelines for Deck Officer Training Systems", the functional requirements for a maritime cadet simulator were developed to meet the identified training objectives. Appropriate consideration was given to both the cost and benefits associated with the various levels of each simulator characteristic (e.g., time of day: day vs night).

4. Development of Training Program Recommendations. Once the functional requirements for the cadet simulator were established, recommendations for the integration of this type of training into the academics' training programs, and the qualifications for the instructor, were developed. These recommendations were also based primarily on the information contained in the "Guidelines for Deck Officer Training Systems".

The above four steps follow directly from the guidelines. Whereas the training needs in the guidelines were developed from masters-level training objectives and an analysis of shipping accidents, those for cadets were based on an independent analysis. The specific guidance information in the guidelines was used heavily since it is generic. The guideline recommendations (e.g., Table 3) were generally not used since they are specific to the master's level. Rather, independent recommendations were arrived at specific to the cadet-level. The remainder of this paper addresses the findings and recommendations for the cadet ship bridge/shiphandling simulator-based training.

General Findings

The majority of the identified cadet training objectives can be trained at sea, although this may not be the most cost effective training medium for many of the desired skills. Many of the cadet training objectives can be effectively taught only at sea, while others are best trained at sea although other media would also be effective. Finally, a subset of the training objectives were found to be best-trained via a ship bridge/shiphandling simulator. These judgements were arrived at on the basis of the simulator capabilities and limitations provided in the guidelines, and the judgements of mariner and training experts. Note that cost was not a detailed consideration at this stage of analysis, but was brought in later when trade-offs were made regarding alternative fidelity levels of simulator characteristics.

Recommendations For Simulator Characteristics

Fourteen critical characteristics were identified for the functional design of a maritime cadet ship bridge/shiphandling training device. A specific level for each of these characteristics has been recommended as a minimum for meeting the needs of cadet training, on the basis of their cost and training effectiveness. A brief explanation and rationale summary for selection of each level of these critical characteristics follows. Considerably more rationale and descriptive information on these functional simulator characteristics is contained in the project report.(6) (Note that the relative cost factors given below are associated with particular training device subsystems, not the overall device cost.

- Visual scene time of day -- Night -- much of the requisite cadet training could be achieved under either night or day conditions; the night capability is estimated to cost about 2.5 times less than the day/night capability; the academies have a limited amount of time available, and nighttime is the more difficult condition.

- Visual scene geographic area -- Coastal -- the majority of highly critical simulator-best training objectives for cadets do not require shiphandling skill in restricted waters; cost is substantially less for coastal (i.e., about 40 percent less).

- Visual scene horizontal field of view -- 180 Degrees -- adequate horizontal separation of geographic objects across a sufficient number of training exercises is necessary to ensure proper development and generalizability of the associated visual position-fixing skills; will cover all the critical meeting and fine crossing situations called for by training objectives; and is necessary for coastal navigation/piloting skills.

- Visual scene vertical field of view -- 20 Degrees -- several critical training objectives require a moderate vertical field of view to handle close-in traffic vessels; a large vertical field of view is unnecessary in a nighttime situation since the upper and lower bounded edges would be unnoticeable.

- Visual scene color -- Multicolor -- a night-only visual scene should have multicolor; research indications are that color is desirable for high workloads; the additional cost for multicolor under nighttime conditions may not be substantial.

- Visual scene quality -- Moderate Quality -- this characteristic depends upon the interaction of many parameters, each of which could vary widely and be acceptable depending upon the level of the other interacting parameters (e.g., brightness and contrast ratio); the complexity of the visual scene, the large number of relevant parameters, and the lack of definitive research information precludes detailed specification at this time; rather, specific proposed visual scenes should be evaluated for their quality at the time of proposal evaluation; guidance principles for evaluating visual scene quality are included in the project report.

- Radar presentation -- Low Fidelity -- the acceptable low fidelity radar would be a real-time updated picture generated by a general purpose computer-display system, with the display located in the wheelhouse in place of a commercially available radar unit; low fidelity radar presentation would be satisfactory for achievement of nearly all highly critical training objectives; high fidelity radar would require a nearly four-fold increment in cost; the academies have high fidelity radar simulators presently for part-task training.

- Bridge configuration -- Full Bridge -- the full bridge would consist of a normal pilot house layout with appropriate equipment and instruments; adequate bridge size is required to handle the anticipated bridge team; a reduced bridge size may result in irregular third mate behavior due to an abnormal pilothouse layout; detailed functional requirements for bridge equipment are contained in the project report.

- Ownship characteristics and dynamics -- Deep Water -- deep water is sufficient for training the majority of the highly critical training objectives; the additional cost for shallow water effects does not appear warranted in view of the minimal training objectives gained; additional hydrodynamic requirements are specified in the project report.

- Exercise control -- Instructor Exercise Control -- this level enables shipboard casualties and other conditions (e.g., wind, current) to be controlled in real-time from an instructor/operator console, rather than have all aspects of the problem always preprogrammed; substantially greater training flexibility at a relatively small increase in cost.

- Traffic vessel control -- Independently Maneuverable Traffic -- necessary for interaction between ownship and traffic vessels, particularly intership communications (e.g., radiotelephone); this would be a very minor increase in cost above the lower fidelity levels for this characteristic in several simulation technologies.

- Training assistance technology -- Remote Monitoring -- displays and readouts placed in a classroom to enable a group of students to monitor and discuss the scenario situation and activities of the bridge team while the problem is in progress; would enable the simultaneous training of multiple bridge teams; research has shown this to be a highly desirable capability.(4)

- Training assistance technology -- Feedback Displays -- a display located in the classroom presenting detailed information concerning the just completed simulator exercise; enables a variety of training/investigative activities to take place in the classroom; research has shown this to greatly increase the cost-effectiveness of training.(8)

- Availability -- the simulator design goal is for operational training to be conducted thirty hours per week with 95 percent availability; an additional 10 hours per week was allotted to maintenance time; vendor support of the simulator was recommended with assistance from an academy staff technician.

Training Device Cost

To estimate the likely cadet training device costs, the developed functional requirements were reviewed by several individuals who were recognized as knowledgeable in simulator design. Based on their input the following cost estimates were developed for the recommended training device.

- Initial System Procurement

  Lowest possible cost = $1.5M
  Highest possible cost = $3.5M
  Most Likely cost = $2.7M

- Annual Operating/Maintenance

  Lowest possible cost = $180K
  Highest possible cost = $320K
  Most Likely cost = $220K

The above figures are provided in 1982 dollars. They assume that a suitable building exists at the specific maritime academy to house the simulator facility. They also assume that the single instructor required for training/system operation and the single technician required for maintenance will be obtained from the academy's staff.

Training Program Recommendations

Training program recommendations were made to assist in the integration of a ship bridge/shiphandling simlator-based training program into the academies' curricula. It is essential that the training device is accompanied by appropriate supporting training materials, guidance information concerning its use, and application assistance when provided to the academies. In order to establish a common basis for the effective integration of simulator-based training into the maritime academy curriculum, the curricula of the state academies were compared. As a result of this comparison a number of observations were made which form the basis for the training program recommendations contained in the project report. The following is a summary of these observations:

- Each of the state maritime academies appear to have four distinct training periods within their curricula. These training periods are:

  - From academy entry to first at-sea period
  - From first at-sea period to second at-sea period
  - From second at-sea period to third at-sea period
  - From third at-sea period to graduation

- Each academy offers a radar observer course utilizing its radar simulator training facility. This course is usually given in the junior (2nd class) year, although one academy offers the course to seniors (1st class).

- Several academies have indicated concern relating to the integration of additional simulator training into the already intensive cadet schedule.

After careful consideration of the similarities identified above and with due respect for the individual state academy's ability to determine the proper means of integrating ship bridge/shiphandling simulator training into their own curriculum, appropriate recommendations were made. The following is a summary of the training program recommendations contained in the project report.

- The academies should consider grouping the training objectives previously identified into four training modules which are described in the project report.

  - Module #1: Basic Watchstanding...prior to first at-sea period
  - Module #2: Coastal Navigation...prior to second at-sea period
  - Module #3: Collision Avoidance...after radar simulator course, prior to third at-sea period
  - Module #4: Advanced Watchstanding...prior to graduation

- Each training module should consist of a series of simulator exercise periods, each approximately 3 hours in duration. The individual academy staff should have the option to either (a) integrate these simulator exercise periods into the existing course as laboratory periods or (b) provide all the simulator exercise periods with each training module as a new course.

- The simulator training should be related to the types of tasks that the cadet will be performing during the next at-sea period. For example, Module #1 should precede the first at-sea training period.

- A carefully structured training program should be employed for maritime cadet training. The project report provides appropriate guidance for the following critical training program characteristics as specifically applied for cadet training:

  - Training Objectives
  - Training Techniques
  - Instructor's Guide
  - Classroom Support Materials
  - Simulator/Classroom Mix
  - Training Program Duration
  - Class Size
  - Scenario Design

- The instructor is extremely critical for effective training. The project report lists and discusses the following critical instructor qualifications/characteristics to assist in the proper selection and preparation of maritime cadet instructors:

  - Mariner Credentials
  - Instructor Credentials
  - Nautical Science Knowledge
  - Instructor Skills
  - Instructor Attitude
  - Student Rapport
  - Instructor Training
  - Number of Instructors
  - Instructor Evaluation

SUMMARY

The availability of simulation technology and the use of ship bridge/shiphandling simulators for the training of merchant marine deck officers has rapidly taken place during the past decade. This has evolved to fill a need created by world-wide increase in shipping, shipping casualties, and the consequences of these accidents. The Training and Licensing Project was initiated by the U.S. Coast Guard and U.S. Maritime Administration to define the role of the ship bridge/shiphandling simulator in the deck officer Training and Licensing process. A major product eminating from this multi-year project, culminating a substantial amount of research, is a set of guidelines for the design of deck officer training systems. These guidelines are aimed specifically at the user of simulator-based training in the maritime industry (e.g., shipping company, labor organization). The guidelines are written at a level to be used by individuals making major decisions regarding the use of simulator-based training programs, who are often not familiar with the engineering and training technologies associated with simulator-based training systems, and who are concerned with the achievement of operational training goals. The guidelines provide a generic structure that is applicable across various deck officer license levels, training types (e.g., transition, refresher, upgrading) and other necessary criteria established by the user. The guidelines establish specific training needs. In the context of the masters-level deck officer for which the guidelines were initially developed, the training needs are based on (1) training objectives amenable to simulator-based training, and (2) high priority areas of human performance as determined from analysis of shipping accidents. The three major parts of the training system are addressed, including (1) the training device, consisting of a simulator and other instructional aids; (2) the training program, and (3) the instructor. Critical characteristics are identified for each of these training system parts; three levels of fidelity or quality are identified for each of the characteristics. Guidance information regarding the available design technologies, their capabilities and limitations, and other issues are provided concerning each of the alternative fidelity/quality levels for each training system characteristics. Finally, a set of specific recommendations are made for the design of a training system to meet masters level training; these are specified in terms of a recommended level and a minimum acceptable level for each training system characteristic; the training system characteristics are further recommended separately for each of the six major areas of training.

An applied example of the application of the guidelines is discussed. This application was devoted to the development of a functional specification for a ship bridge/shiphandling simulator for the training of maritime academy cadets. This initial application of the guidelines addresses not only the design characteristics of the training device, but also the development of guidance material for use by the maritime academies for integration of the simulator-based training into their curriculum, and for the development of an effective training program to support the simulator-based training.

APPENDIX A. EXAMPLE GUIDELINES CONTENT FOR SIMULATOR DESIGN CRITICAL CHARACTERISTIC, VISUAL SCENE, HORIZONTAL FIELD OF VIEW

Horizontal Field of View

The horizontal field of view required for a shiphandling/navigation simulator should depend on the specific objectives of the training program. If the visual cues required to execute a particular shiphandling maneuver are within a relatively narrow field of view, such as when training the skill of utilizing range lights, a reduced field of view is satisfactory and may even be preferable since it artificially focuses the trainee's attention on the required visual cues. However, prudent training practice would indicate that the student should then be trained in utilizing this skill under conditions with operational noise and distractions; for example, identifying the range lights and concentrating on them among the background lights and distracting traffic vessel movement. This type of training could then imply a requirement for greater horizontal field of view than that identified for the development of the basic skill. Consideration should also be given to the utilization of a variable horizontal field of view in order to gain the training leverage discussed above.

The cost of a ship bridge/shiphandling simulator increases as the horizontal field of view increases. This increase in cost results not only from increased projection equipment costs but also from increased processing hardware and software costs. This is particularly true for computer-generated graphic systems.

<u>Level I: Greater than 90°, less than 120°.</u> Use of this horizontal field of view may be satisfactory for training a limited number of specific shiphandling skills (e.g., range lights, buoyed channels). It may also be satisfactory for training the application of the rules of the road in meeting and fine crossing situations. However, if it is employed in broader crossing situations or overtaking situations where visual contact is lost with the traffic vessel, there may be a danger that the trainees will have a tendency to neglect visual bearings and rely heavily on radar in these types of scenarios. A horizontal field of view of less than 120 degrees is generally unacceptable for training skills that involve visual position fixing since adequate horizontal angular separation of suitable geographic points suitable for a visual fix can not be obtained except for possibly a few unique cases. In this same light, such a limited horizontal field of view also precludes the development of skills in the use of turn bearings. There may, however, be some training value for a horizontal field of view of less than 120 degrees in the development of skills involving the integration of visual lines of position with radar information or other electronic navigation information, although the trainee may be inadvertently trained to neglect the more advantageous objects abeam for visual bearings.

<u>Level II: Greater than 120°, less than 240°.</u> Use of this horizontal field of view appears appropriate for the majority of the desired skills categories identified earlier. It may, however, be limited if visual bearings abaft ± 120 degrees relative are important for navigation in a particular port. In addition, the application of the rules of the road in an overtaking situation is also constrained, although only for the situation when ownship is being overtaken and not when ownship is doing the overtaking. This situation, however, is somewhat unique and not particularly difficult (i.e., requiring specific training) since it usually involves a relatively slow closing rate which allows substantial time for analysis and action.

<u>Level III: Greater than 240°.</u> Use of a horizontal field of view of this magnitude may be appropriate if the development of skills involving the following factors are deemed to be important:

- Vessel with pilothouse forward (i.e., ore carriers)
- Use of rear ranges
- Use of visual bearings abaft ± 120 degrees relative (e.g., specific port requirement)

It should be noted that many of the visual scene generating technologies have the capability, particularly if considered during the initial design, of optically/electronically rotating the fixed visual scene to provide visual cues in areas not normally considered possible with that design. For example, Figure 1 illustrates a 240° horizontal field of view providing a visual scene from 30 degrees left of ownship's heading to 30 degrees beyond dead astern. This may be particularly desirable during coastwise navigation exercises to facilitate the use of visual bearings, or when approaching and picking up a tow. This flexibility with the simulated visual scene should be used cautiously since it alters the bridge environment's proper orientation with the visual scene (i.e., front of pilothouse faces side of vessel). The impact of this effect on the training provided is unknown.

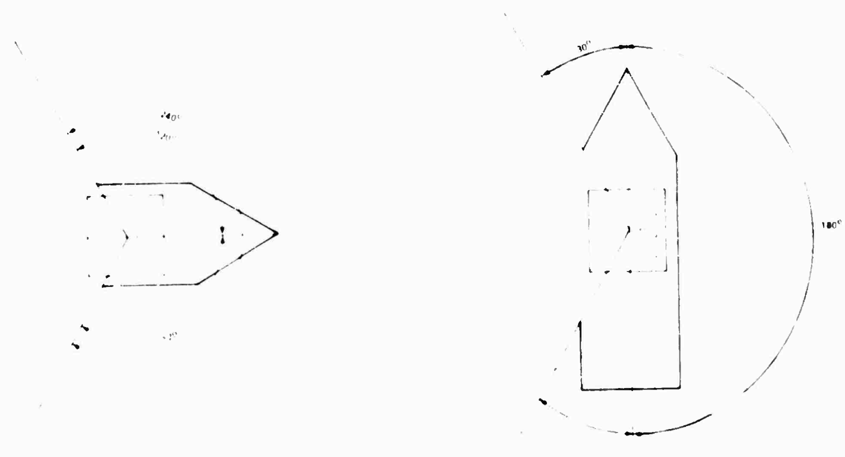

Figure 1. Rotation of Visual Scene

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CAI/CMI: HOW MUCH IS ENOUGH?

by

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ABSTRACT

Computer Aided Instruction and Computer Managed Instruction (CAI/CMI) provide training systems with a wide assortment of capabilities. These capabilities range from simply recording a student's progress to eliminating the need for a full time instructor. This paper explains the methodology used to determine the amount of CAI/CMI necessary to support the needs of the user. It also discusses the management of the interaction and coordination of the CAI/CMI design with other trainer design elements. The NTDS Laboratory Trainer - Device 20F17 is referred to as a quantitative example of managing CAI/CMI development. In the development of Device 20F17, the courseware developer's involvement allowed for the early definition of the amount of CAI/CMI needed and the degree of automation required. This timely input in the proposal phase influenced the hardware and software design to accommodate the CAI/CMI needs, thus minimizing the cost of including these features.

INTRODUCTION

As the sophistication of training tasks has increased, the necessity for greater involvement of the computer as an assistant to the instructor has likewise increased. Since many tasks cannot be taught solely in a classroom environment, computer based training systems have proven they can significantly improve the quality of learning.

The computer has also been used to promote the capabilities of the laboratory instructor. Many skills are difficult to explain in the laboratory by an instructor; a computer based system can demonstrate these for him. The computer can also assist the laboratory instructor in evaluation of student performance, thus improving his productivity.

With the rise of Computer Aided Instruction there has been a fragmented approach to implementation methodology. CAI has been implemented in many training devices over the past few years to varying degrees and with varying success. In many cases the implementations have not met the preconceived goals. In other cases the costs have been far above original estimates. However, in some situations the CAI has been properly implemented for a reasonable cost.

This paper will attempt to define a methodology to guide the CAI implementation decision.

DEFINITION

Computer Aided Instruction (CAI) is a tool or strategy used to teach cognitive and psychomotor competencies. A CAI training system offers individualized instruction to a student without having an instructor present at all times. CAI is sometimes referred to as Computer Based Instruction (CBI) and may be divided into two categories: Computer Aided Instruction (CAI) and Computer Managed Instruction (CMI).

Capabilities of CAI

CAI includes the ability to generate a learning environment, provide instruction, and allow practice sessions. The capabilities derived from CAI include simulation, stimulation, cues, prompts, and feedback.

For the purposes of this paper it is appropriate to divide CAI into intrinsic and extrinsic capabilities. Intrinsic capabilities are those skills that a trainee would receive from operating simulated and/or stimulated equipment. Computer simulation is capable of generating a learning or operational environment. Simulation is considered to have moderate training realism, is cost effective, and is easily implemented. Stimulation uses operational equipment which provides a higher degree of training realism. The increased fidelity typically requires higher acquisition cost and creates a more difficult implementation. Stimulation has an additional advantage in that it uses actual equipment with operational software and can easily be upgraded.

Extrinsic capabilities add to a learning environment by offering knowledge of results. It includes cues, prompts, and feedback. Cues and prompts guide the student toward errorless learning while feedback allows the student to learn from his mistakes. Extrinsic cues, prompts, and feedback should be replaced by intrinsic feedback as proficiency increases.

Capabilities of CMI

CMI does the busy work for the instructor. It allows more time for the instructor to help the student develop desired techniques. It also has the potential to decrease the number of instructors required. CMI includes computer aided grading, record keeping, and exercise control.

Computer aided grading, or automated performance measurement, is a CMI function that provides a means to grade the trainee actions objectively. Instruction based on test samples can modify the learning path according to the specific training methods employed. For example, three such training methods are Linear, Intrinsic Branching, and Mathetics. The Linear Method (1), developed by B.F. Skinner, provides sequenced instruction in small steps where the student is trained to respond to a given stimulus. The Intrinsic Branching Method (2), developed by N.A. Crowder, allows for student mistakes and adjusts the instruction to the learner's needs. The Mathetics Method (3), developed by T. Gilbert, is a methodical approach that properly arranges key points to ensure learning.

Computer aided record keeping can be used to track students through an entire school curriculum or just for an individual session. A by-product of computer aided record keeping is the establishment of trainee historical data.

As an exercise controller, CMI can generate the initial environmental conditions, control each exercise event, or any combination in between. The computer can manage an entire training session where each exercise event is controlled by the CMI system or be used to only establish initial conditions.

Limitations and Disadvantages of CAI

Although CAI is effective in many teaching situations, several inherent limitations and disadvantages exist. Consequently, these limitations must be evaluated when considering the incorporation of CAI in a training system. CAI is not suited to teach all learning competencies. It is not well suited for teaching items such as volitional (will), affective (emotions/feelings), interpersonal and judgemental skills.

Any skill that requires human interaction to develop self-esteem requires a sensitive learning environment. Volitional and affective competencies present a real challenge to a learning system due to their interpersonal requirements. Teaching judgmental skills, the ability of the student to determine alternatives, is also difficult to automate. Each task must be well documented and the objectives must be stated in measurable behavioral terms. Documenting these tasks, objectives, and standards require analysis which normally causes development cost and schedule to be prohibitive.

Another disadvantage of CAI is the lack of flexibility of the curriculum. When designing a training system, flexibility must be considered. An instructor can modify a lesson as it is being presented while automated systems are only as flexible as their design allows. More flexibility means additional development time and cost.

SELECTION METHODOLOGY

Before selecting the computer as a training tool, the task itself must be considered. The task to be analyzed must be well defined and measurable. Task definition is done in a task analysis by personnel trained in analysis procedures.

Task Analysis

A task analysis identifies the jobs that need to be performed in the operational environment. It also defines the conditions under which the task must be performed and the standards that tell when the task is mastered. Some tasks, such as perceptual, volitional, affective and judgemental tasks are not observable and cannot be graded directly. These types of tasks should be taught using group interaction. Tasks that should be considered for CAI/CMI instruction are those requiring cognitive and psychomotor skills. Each defined task must include main intent objectives or indicators. Indicators that can be graded must be developed to confirm that the learner has performed an unobservable task.

Method Means Analysis

After completion of the task analysis, a method means analysis should be performed. A method means analysis is defined as a listing of possible teaching methods available to the developer. This listing includes the various teaching methods and then identifies advantages and disadvantages inherent in each method. The selection of a teaching method should be matched to the task itself. Questions that are asked during a method means analysis include:

- What is the task?
- What methods are realistic to teach the task?
- What are the advantages/disadvantages of each method?

Method selection should not stop at one choice. Alternative methods must be considered as well as a combination of methods. Teaching using CAI is one available method to consider.

The determination of whether a combined approach is feasible generally becomes apparent during the method means analysis stage. Examples of some general strategy selection rules are:

- Review alternate methods to teach a subject.

- Strive to use a combination of teaching strategies.

- Aim to add novelty to the teaching method.

At first, the computer was viewed as a way to reinstitute individualized teaching. The computer was introduced as a panacea to curb training costs, increase standardization, decrease training time, and increase training effectiveness. Unfortunately, in some cases, the computer was seen as a replacement for the teacher. Just as the book does not replace the teacher, the computer will not replace the teacher. The teacher's role continues to change and the computer can be used to supplement and complement the teacher.

Teaching a task with conventional manual methods is the alternative to automation. An effective combination scheme frequently includes computers and conventional teaching methods. A methods means analysis will indicate this type of strategy if both schemes prove appropriate for teaching the desired skill.

In all cases, the computer should be considered for teaching mundane tasks, presenting prearranged situations, and leading the learner through a series of related competencies while the computer grades and evaluates the progress. Interpersonal skills, tasks that are not well defined or tasks without a complete task listing, should generally be considered for teaching by an instructor.

The Implementation Decision

One output of the task analysis and method means analysis is a recommendation to include CAI as part of the teaching process. While the range of CAI implementation techniques can span the complete range of automated system capabilities, a reduced group of training system unique items has been cataloged. These training features include:

1. Exercise Control - The computer provides pre-programmed initial scenario conditions. More extensive implementations can include computer-control timed events and/or allow for instructor intervention at any time.

2. Prompts - Alphanumeric cues are given to a student to direct his attention towards specific learning objectives within a scenario.

3. Instruction - Detailed lessons are given on the computer for individualized learning.

4. Performance Measurement - The evaluation of the student's progress is performed by computer controlled and evaluated tests.

5. Feedback - Messages or alerts are provided to inform the student when a mistake has been made or a task has been performed correctly.

6. Performance Printout - A hard copy of the performance measurement results for a single scenario.

7. Branching - The pace and structure of the lesson are altered based on specific student responses. Incorrect responses can initiate retries or specific remedial portions of the scenario.

8. Performance Recording - Recording of student's records and grade data for a full class. Maintenance of a data base on the history of the classes can be included.

The training system designer should review each of these CAI features against the method means analysis to determine the applicability for the selected training problem. Each training feature should be reviewed and a cost/benefit evaluation made. Figure 1 shows a flowchart approach to the degree of CAI implementation methodology. The capabilities are placed in a hierarchical sequence so the selection process stops once a no response occurs. At this point you have defined the training system CAI capabilities. For example, if one chooses to include exercise control, prompts, instruction, and performance measurement but not feedback, the CAI capability of the system is then defined. No other features can be implemented without a feedback capability.

After determination has been made as to the extent of CAI implementation, an overall review is in order. The question must be asked, "Should CAI be implemented even if it can be?" The factors needed to perform this analysis fall into two categories: performance and cost. CAI must be justified on one of these two grounds.

The first evaluation factor is improvement in teaching. In many cases CAI will improve the quality of the instruction thereby increasing the proficiency level of the graduate. As a result, educators may eliminate or decrease the amount of time spent on later training. In other cases, significant improvement in the effectiveness of the graduates can be achieved. Further, CAI may be the only way to produce a course graduate that is capable of performing to the level defined in the task analysis. In other cases, CAI may improve the quality of the course to allow a higher percentage of students to pass.

The second basis for consideration of CAI is cost. The cost here is the ultimate life cycle cost of training. The addition of CAI features may significantly reduce the quantity of instructors needed to teach a course. For example, in the case of the Electronic Equipment Maintenance Trainer (EEMT) Device 11B106 the staff for the Electronics Technician (ET) school at Great Lakes had a student to instructor ratio of 6:1. After adding EEMT the ratio increased to 10:1. As a second example, in Device 20F17, the NTDS Laboratory, the inclusion of these features allows a student to instructor ratio of 4:1, a significantly better ratio than would otherwise be possible.

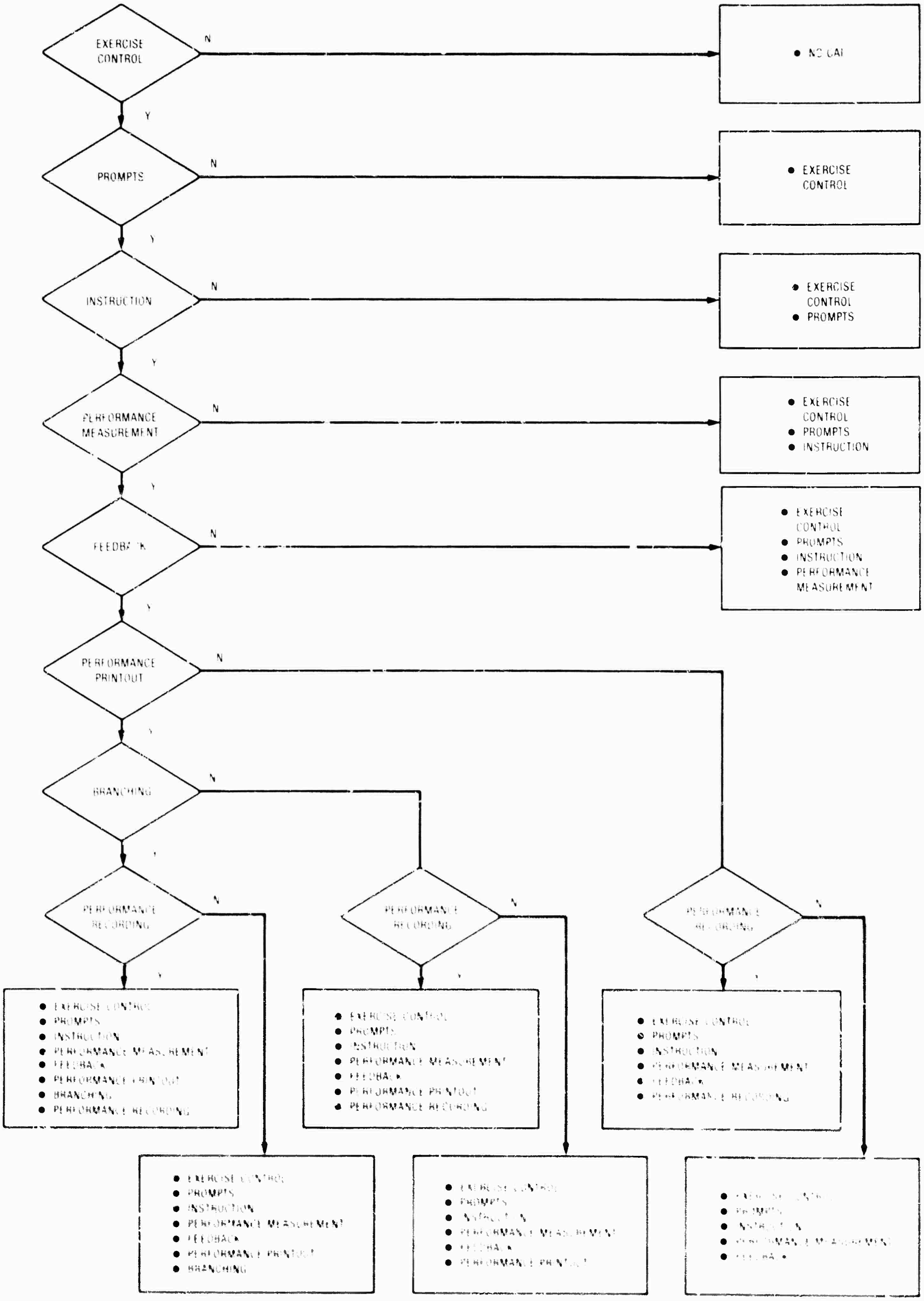

Figure 1 CAI Feature Selection

As was stated above, the inclusion of CAI can not only improve the quality of the graduate, but minimize the need for follow-up training. CAI features can also be used to minimize the orientation time of instructors with the training device. A menu-driven system written in the user's language simplifies operation. This may allow for decreased device specific instructor training.

When to Implement CAI

If an analysis of the particular learning situation has indicated that CAI should be incorporated as part of the training device, the next logical step is to ascertain when the CAI should be incorporated. This decision can be reflected in the specification, which should define the amount of CAI required.

However, the supplier of the training device controls the management strategy for CAI. This strategy includes deciding the timing of the involvement of the courseware developers. In cases where the generation of training scenarios is required early in the development process, the timing is significant. In other cases the courseware developers might not be needed until the device design has proceeded past the critical design review stage.

There are, however, significant risks in allowing the design architecture to be frozen without a full evaluation of the effects of CAI on the trainer. In addition, the courseware developers can provide a voice representing the user within the contractor's project organization.

While it may be tempting to delay the use of the courseware developers to save cost, there is a penalty for this approach. When the courseware developers are early participants in the project team, they can make significant observations regarding deficiencies in the trainer architecture. Any gaps may prohibit the efficient and effective implementation of the CAI required by the specification. The involvement of the courseware developers during the system design phase can improve the quality of the overall training device design and reduce the total implementation cost.

DEVICE 20F17 EXAMPLE

An example of how CAI/CMI was selected and implemented is the Device 20F17 (NTDS Laboratory). It was designed as a generic basic operator skills simulator using levels of achievement to teach simple to complex tasks in a sequential order. Figure 2 is an artist's concept of Device 20F17.

System Description

The NTDS Laboratory was designed to simulate the OJ-194-(V)/UYA-4(V) PPI Data Display Console in all respects. The device provides dynamic training in the visual and tactile responses required to achieve the NTDS console manipulative and interpretive skills necessary to stand a Condition III (Normal Peacetime Steaming) watch with supervision. The device consists of 64 operator trainee stations grouped into sixteen stand-alone suites. Each suite contains four simulated OJ-194(V)/UYA-4(V) look-alike PPI consoles, four simulated AN/UPA-59(V)2 look-alike IFF decoders, and a mini-computer with associated peripherals and interfaces. One of the 16 suites is classified as the master, which is capable of scenario generation. The configuration of a typical student suite is shown in Figure 3. The device contract also requires computer operational software to control the trainer, 60 hours of preprogrammed scenarios with associated courseware, and all classroom and laboratory curriculum. The trainer software also emulates a DDG-37 class NTDS operational program.

Input/User Mode

The OJ-194(V) PPI look-alike console is capable of responding to input/user operations which deal primarily with evaluation of NTDS data to supplement the tactical decision making process. User functions are performed by such operators as Force Weapons Coordinator, Ship Weapons Coordinator and Air Intercept Controllers. Input functions include air detector tracker, surface/subsurface tracker, identification operator and track supervisor. A typical PPI display seen by these operators is shown in Figure 4.

Tactical Scenarios

Preprogrammed computer generated scenarios have been developed to portray specific tactical situations within the confines of the tactical environment. The scenarios emphasize input operator responses and are structured to provide fifteen separate levels of achievement. Scenarios permit instructor intervention to freeze and replay at any 5 minute operating point during instruction. The instructor is also able to select scenario speed from a range of 1X, 2X, and 4X normal operating speed. The device is designed to enable operation of a common scenario within a four console suite. Each scenario independently responds in real-time to the respective operator console interactions. The PPI display provides realistic video displays of targets and media as well as full NTDS symboloby.

Target Dynamics

The device has the capability to maintain track data, provide motion simulation, and display in real-time up to 24 active exercise vehicles (targets) simultaneously per console. Each of these targets is pre-programmed as a specific type of air, surface, or sub-surface target with defined course, speed, altitude and maneuvering parameters.

Target Behavior

Preprogrammed air launch platforms are simulated with initial course, speed, and altitude, and each has unlimited time-designated inflection points where preselected course/speed changes automatically occur. Air, surface, or subsurface launched antiship cruise missiles (ASCM) follow altitude flight profiles similar to those of

NTDS LABORATORY TRAINER-DEVICE 20F17

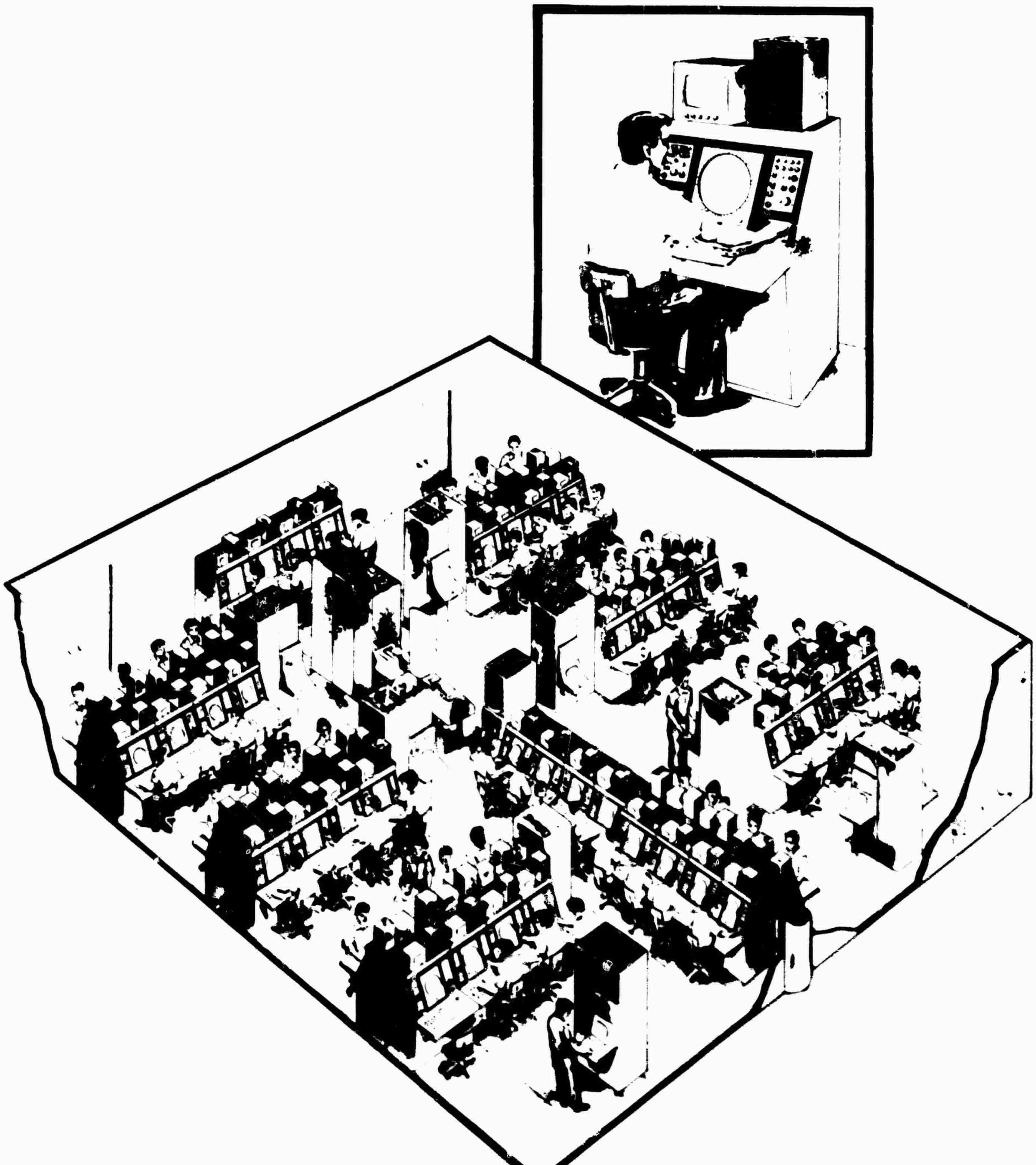

Figure 2 Artist Sketch

Figure 3 Student Suite Configuration

Figure 4 PPI Display

actual platforms. The capability exists at the student consoles and in scenarios to assign Identification Friend or Foe (IFF) codes to each air target. Each target has the capability of being designated as an active jammer by the scenarios. The number of active jammers in any one scenario is limited to ten.

Video Display

The device simulates weather clutter, sea return, landmass, barrage jamming effects, chaff, IFF video and symbology. Each is implemented in response to control commands from the preprogramed scenarios for PPI display on the look-alike console.

CAI IMPLEMENTATION FOR DEVICE 20F17

The Device 20F17 was designed as a generic basic operator skills simulator to avoid teaching the ever changing software and the numerous consoles in use in the fleet today. This is possible because the basic jobs of the input operators have not changed in twenty years. Programs and hardware have changed the method of data entry/extraction and in some cases the location of the controls, but the jobs have remained intact. Device 20F17 teaches these basic skills using one console and a generic NTDS software program.

Once the skills are mastered, the students are able to apply this knowledge on different consoles, using different NTDS programs. Generic training allows basic skills training to be insulated from the impact of the continuing changes in operational hardware.

Task Analysis

The Device 20F17 development started in 1977 with a Needs Analysis (4) which was verified in 1980 at the beginning of the present development. The needs analysis defined the input operator's basic skills. Subject matter experts that were trained in instructional systems development were able to work with the NTDS operators at FLECOMBATRACENLANT (Dam Neck, VA) to define the job tasks without a formal task analysis. The task listing was limited to the performance itself; the conditions and standards were not defined. The tasks were sequenced and grouped into levels of achievement. Levels of achievement was a term coined to place a more positive approach to learning than the phrase levels of difficulty. The task analysis also did not define quantitative values for detecting, entering and tracking skills. No objective data on these performance standards was available from the fleet.

Method Means Analysis

The same 1977 analysis study compared alternative methods of teaching the NTDS operator tasks. Advantages and disadvantages of each were listed, including cost. Recommendations for training system selection were made as a part of the study. Each alternative was compared to use of the operational equipment in the trainer and the following alternatives were considered:

1. Look-alike consoles with sixteen computers. This is the approach that was adopted as the Device 20F17.

2. Look-alike consoles with one computer. This approach tied all of the consoles together; however, no provisions were made for degraded mode when the one computer failed.

3. A slide-tape training system. The cost was fairly low; however, the tactile "feel" and capability for future expansion was limited.

4. Operational equipment driven by a simulator was considered. The fidelity was good; however, the cost was excessive.

CAI Features

Since the quantity of students requiring training in NTDS basic operator skills exceeds 2000 per year, it was determined that reduction in the instructor's workload was important; an instructor to student ratio of 1:4 was dictated. This requirement then led to consideration of various CAI features to aid the instructor and provide supplementary tutoring to the students.

A comparison of the flowchart approach of Figure 1 to the needs of Device 20F17 demonstrates the process of consideration of CAI features for a trainer. In order to reduce the instructor's workload during laboratory sessions, it was decided to use preprogramed scenarios (EXERCISE CONTROL). Since one instructor cannot be constantly in contact with all four students, computer generated messages on an instructional/tactical CRT (PROMPTS) synchronized to the scenario was provided. The student's learning process was also enhanced by the inclusion of capabilities for computer display of detailed step-by-step procedures (INSTRUCTION) synchronized to the scenario. Since many of the skills such as ball tab positioning accuracy can be quantified, computer generated tests and evaluation of student behavior (PERFORMANCE MEASUREMENT) was included. The timing of these tests was also controlled by the scenario. It was also concluded that real-time results of these tests (FEEDBACK) should be available to the student in the early phase of training. The scenario author would define whether the test results were to be displayed to the student and/or stored for printout at the end of the lesson (PERFORMANCE PRINTOUT).

Other CAI features were then considered. Real-time modification of the lesson based on student proficiency (BRANCHING) was rejected as being more sophisticated than was desired for the trainer. The high student load, necessitating a lock-step curriculum was partially in conflict with BRANCHING, where the lesson time can vary from student to student. The additional implementation cost, courseware development time, and program risk were also factors in the decision. The establishment of a historical data base (PERFORMANCE RECORDING) was considered, but viewed as beyond the scope of the training requirements.

Involvement of the Courseware Developers

The courseware developers, if not subject matter experts, had to learn the tasks being taught so they could synthesize the material. They were intimate with the user's language, equipment, and job. Courseware developers that were knowledgeable of equipment operations and performance measurement requirements assisted in the hardware and software development.

In the development of Device 20F17, courseware developers served a valuable role in representing, within the project team, the needs of the user. Since the motivation of the courseware developer paralleled those of the user, the influences provided by the courseware personnel allowed the project design to better reflect the user's desires. This participation in the design concept incorporated subtleties in the training device which maximized its training effectiveness.

Effects on Hardware Design

Courseware developers on Device 20F17 assisted in defining the hardware requirements needed for performance measurement. All hardware controls and indicators are not needed to operate as the actual equipment functions. By defining which controls and indicators are needed for the degree of authenticity required, the hardware design and construction was simplified with a corresponding cost savings.

The Device 20F17 hardware design architecture allowed for many variations of hardware design. One design approach considered used an intelligent look-alike console with significant processing power located at each console. While this approach is acceptable from an implementation perspective, it complicates the task of analyzing all student inputs and providing quantitative performance evaluation. The CAI requirement which was included in the contract specification directed the hardware design towards a dumb look-alike console with all student switch and control actions available to the host simulation computer. This hardware design decision simplified the incorporation of CAI throughout the trainer. It provided operator inputs and responses to the software, thereby simplifying the task of implementing the CAI software.

Courseware Developers Influence on Software

The CAI unique software requirements for Device 20F17 included an offline scenario generation program to allow scenario authors, with little computer background, to generate scenarios. In addition, real time programs implemented specifically for CAI provide:

- Prompts to be displayed for the student.
- On-line feedback messages to the student.
- Real time performance measurement.
- Post exercise performance printouts.

This substantial software effort was significantly impacted by the courseware developers. Discussions with the software project engineer and the program manager resulted in modifications to the original design concepts. These modifications made the programs more usable to the courseware developers and thus simplified their job. Those changes also simplify the user's job to modify the delivered courseware or generate new scenarios as required.

The most striking changes occurred in the scenario generation program. With the influence of courseware people, the scenario development program evolved into a user oriented authoring system. The user is led through the program and prompted for appropriate entries by a sophisticated generation and editing capability. The program also includes scenario verification and error checking to insure that preprogramed targets are maintained within a realistic environment; i.e. surface ships do not cross a land edge barrier.

The performance measurement program was also significantly enhanced and provides sophisticated and meaningful performance measurement for a wide range of significant trainee measurement situations.

SUMMARY

Computer Aided Instruction has been firmly established as a requirement in many existing and future training devices. It can significantly improve the training capability when properly implemented.

This paper has presented a simplified approach which can assist in making critical CAI implementation decisions. The examples of CAI features on Device 20F17 provide lessons which can be applied to other training applications. With the proper approach CAI can enhance almost any trainer.

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COMPUTER PROGRAM DOCUMENTATION - WHAT IS OVERKILL?

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ABSTRACT

Millions of government dollars are being spent on documentation of the computer program systems of Aircrew Training Devices every year under the premise of life cycle support. As the costs of Aircrew Training Devices increase, it becomes imperative that a complete evaluation be done to decrease documentation costs. This paper discusses the following components of the documentation issue.

(a) What documentation is necessary for development and acquisition tracking? Do we use it?

(b) What documentation is necessary for three major manning levels during support?

(c) How much is "blue suit" maintenance costing as part of ATD?

(d) Commercial Practices Documentation - is it any good?

(e) Will computerization save us?

(f) Where can dollars be shaved?

INTRODUCTION

Since late in 1973, the Air Force has been reemphasizing overall aircrew training to include a higher dependence upon Aircrew Training Devices (ATDs) for accomplishment of simulator unique training. Inherent to this change in emphasis is the increase in total dollars expended on ATD acquisition and follow-on support. As the economy weakens, the cost of people intense tasks continues to increase. Two of the tasks which most effect ATDs are the writing of software programs and subsequent documentation. The ATDs currently procured are more complex and software-intensive than ever before. With this is the overall increase in ATDs cost, and a drive to decrease wherever possible the high cost contributors, so that more devices can be acquired without degradation of overall training effectiveness. This paper defines what documentation is needed for Computer Program System (CPS) Development, acquisition tracking, and the different ATD support philosophies. The cost of organic maintenance is evaluated. In addition, commercial documentation and trends in computerization of CPS documentation are also discussed. Finally, three recommendations are made which would help decrease the total cost of CPS documentation in ATDs.

DEVELOPMENT DOCUMENTATION

What is Needed

The life cycle of an ATD can be divided into two major phases, acquisition and support. Each phase has distinct and different requirements for documentation of the CPS. During the acquisition phase, where the CPS is designed and developed, three tasks are aided by CPS documentation:

(1) Document the development of the CPS and its design;

(2) Program reporting, status, and tracking to the acquisition agency; and

(3) Support testing of the device.

These three tasks generate entirely different requirements for documentation and each will be covered independently.

Design Documentation

The CPS Design Documentation is produced to show how the CPS is developed and what the final design will be. At the Preliminary Design Review (PDR) three areas of the design will be documented. First, the allocation of each system into hardware functions and software functions must be identified and frozen as much as possible. Second, any previously used model which has been selected for use on the ATD must be identified and described. Finally, and most importantly, an overview document must be provided that defines how the system will work.

At each successive design review the design document should become more definative until the Critical Design Review (CDR) when the final version should be complete. After the CDR, since some changes are inevitable, change pages should be issued to support the corresponding design change. The type of documentation required is dependent on the type of functional system. ATD real-time applications consist of two types of systems: one based on a mathematical model of the aircraft, and one which is somewhat task oriented.

Systems based on a mathematical model have special documentation requirements, in both hardware and software, to show design correlation between the real-world system and the simulated system. To document this most explicitly would require two functional block diagrams, equivalent to Figure 1, and supporting narrative descriptions

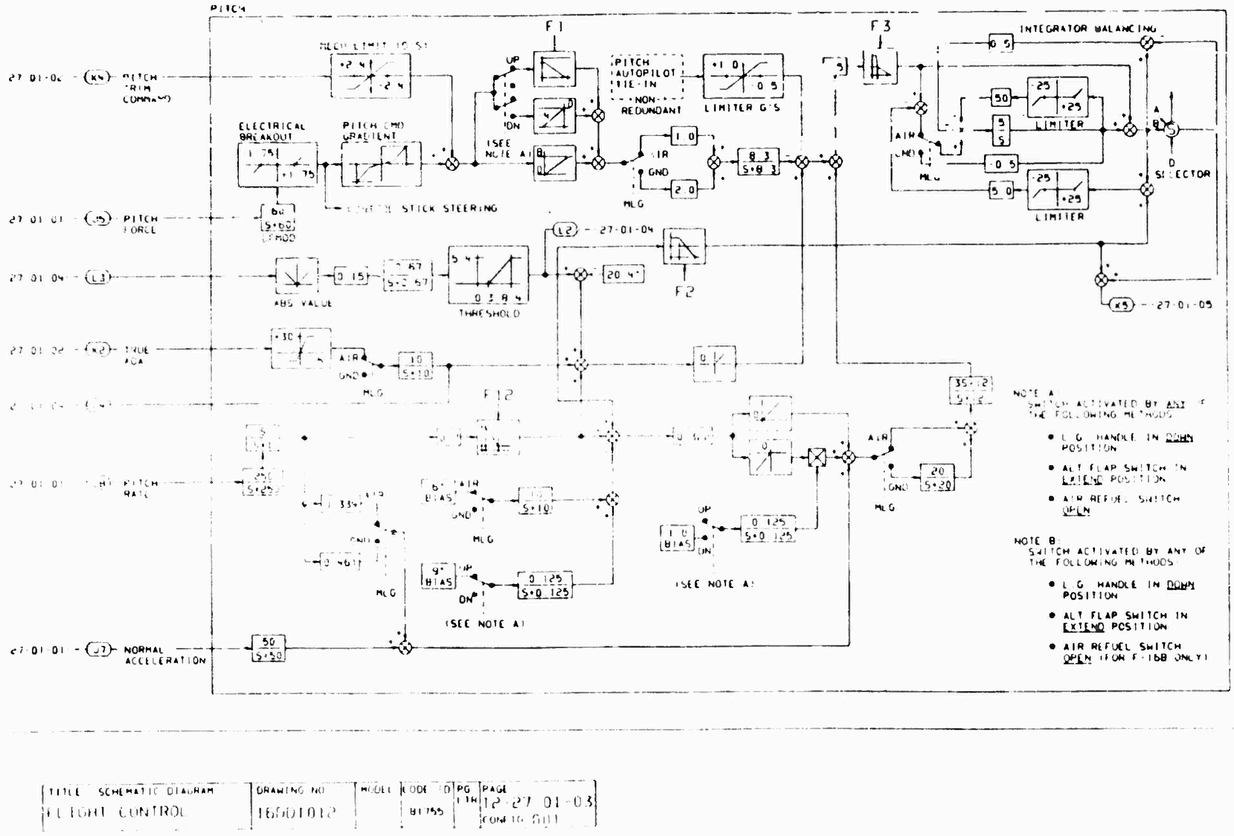

FIGURE 1 FUNCTIONAL BLOCK DIAGRAM

of both the real and simulated systems. This would provide a top level understanding of the design approach, per function, for both contractor and government engineers to follow. A detailed presentation of the simulator system's hardware/software interfaces should be defined. Probably the most important interface would be with a user's guide, and include complete operating procedures. In order for a task oriented system to be defined completely all outside interfaces must first be established and discussed during early design reviews. One obvious and important example would be the instructional aids/controls.

Status Documentation

Documentation necessary to assist the acquisition agency in tracking the development effort is the second type of development documentation required. The System Engineering Management Plan, Computer Program Development Plan and Firmware Development Plan all provide development planning information and schedules to both contractor and government personnel. Other related plans are for Configuration Management and Quality Assurance. When defined completely and used as a rigid model against which development activities are based, these plans are very useful.

Outside of the planning document, additional data should be generated for tracking the CPS. The most widely used is a representation of CPS allocation in a tree form. This provides a guide to how the CPS is designed, a base for implementation of planning documents and size/time tracking. Size/time tracking permits frequent monitoring of critical computer resources.

Test Documentation

Very little additional documentation is necessary to support the ATD testing, as long as the initial design documentation is correct. An alphabetic cross-reference of engineering terms and program mnemonics, units and modules that use/change these variables, is used the most frequently, along with other printouts, such as program listings, memory allocation listings, and data pool lists. The most important issue for test documentation is that it be correct, available, and maintained in a current state.

Do We Use Development Documentation?

All documentation produced during development is utilized to some degree. If design documentation is provided before the design reviews to enable a pre-design review evaluation, then the design reviews become more detailed and comprehensive. This increases government awareness of the design and minimizes surprises as design changes develop and testing begins. Status documentation keeps the government aware of the contractor's progress, even if it is toward a schedule slip. It is far more cost effective to catch such a slip one month after CDR than two months before test. Good test documentation assures a more complete test of the device, for both the contractor and the USAF.

Development documentation is also used as the basis for support documentation. Even commercial documentation is based upon the definition of the CPS product which is internally produced during the development cycle. Additional data items required and specified formats make up all the major differences in support documentation.

SUPPORT DOCUMENTATION

Maintenance Concepts

Normal definitions of maintenance appropriate to hardware are not easily adapted to software maintenance. We can, however, divide software maintenance approaches, including modifications, correction of latent deficiercies and enhancements, between organic (blue suit), hybrid and full contractor maintenance concepts.

In the blue suit concept, mili ir ATD maintenance technicians handle software .)port. Little training, tour length and retencion are the primary contributors toward lack of effectiveness.

A hybrid is a compromise between the total blue suit maintenance and total contractor maintenance. It is based upor the augmentation of the blue suit concept with engineering educated personnel, either government or contractor. With this concept, engineering cap bility is increased and long-term civilian augmentation can resolve problems created by military duty tours and reassignments.

The third level or type of software maintenance is contractor support or Contracted Logistics Support (CLS). Contractor support provides an increase in engineering skilled personnel and consistency in support. Usually, a support team will be staffed by one or two qualified field engineers and augmented by newly graduated engineers, with very little ATD experience. This concept does provide for an experience base to be built, unless the service contract is recompeted within two years and awarded to a second company. Even then, it is not uncommon for incumbent personnel to transfer employment to the second company. This concept has the added advantage of making the originator of the support documentation directly responsible for its adequacy and providing a tie to the originator for additional support when needed.

Support Documentation

Each of the three concepts of software maintenance has different support documentation requirements. Due to limited training and retention, the total blue suit concept has the greatest need for quality documentation and, therefore, has the higher associated cost. The maintenance technicians need to use the documentation both top-down and bottom-up. The top-down study approach is used to teach new technicians about simulation in general, and experienced technicians how the specific ATD system works. For this study approach extra documentation is required to provide simulation technology and development philosophy, as well as detailed step-by-step procedures defining how to use the available software. A bottom-up approach is used when a latent deficiency or proposed enhancement is identified, to track back from listings to what math equations/models are applicable. For this study approach extra documentation is required to provide this backwards tracking since development documentation is evolved going in the opposite direction. Modifications of any size are usually contracted out.

With the addition of engineering personnel, the bottom-up approach is usually eliminated. An understanding of system and basic engineering concepts available for a long term should replace this approach. Small modifications should be supportable with this augmented blue suit concept, even though many of the larger modifications would still be contracted out.

The third level of software support should handle all but major modifications through the contracted support team. Additional documentation for simulation technology and development philosophy would not be required since the two field engineers would be able to instruct other team members. Also, it the field engineers had previously participated as part of the on-site test team, only top level procedures for software usage would be required. Actually, each contract aw rd should include an overlap of contractors to ensure no degradation of support during the transition period from acceptance testing to operational training. The documentation required for CLS is equal in most cases to development documentation.

BLUE SUIT MAINTENANCE COSTS

Reenlistments

One of the greatest differences between the USAF maintenance teams and commercial simulator companies' support teams is the average experience level. This is caused by a decreasing reenlistment statistics trend. In 1981 only twenty-five percent of all first term ATD maintenance technicians (AFSC 341XX) elected to reenlist. This can be compared to a forty-two percent average for all Air Force specialties. This 1981 first term reenlistment also compares poorly with 1979, when thirty-seven percent of ATD maintenance technicians reenlisted. Of all second term ATD maintenance technicians, only forty-three percent reenlisted, compared to seventy-one percent for all specialties. (1)

Training

As each newly enlisted service member attains an AFSC rating he is sent to specialized technical training to master the skills required for full qualification. To train an enlisted member in the ATD maintenance fields (all AFSC 341XX), it will cost an average of $12,477 in 1982 dollars, compared to $8,799 in 1980 dollars (see Table 1). (2) These costs include incentives pay, selective reenlistment bonuses and proficiency pay. They are based on the cost per quaduate for training required at a basic skill level, acquisition costs, basic training costs, pay and allowances while in pretechnical training, permanent change of station after training, and

TABLE 1 ENLISTED PERSONNEL ACQUISITION COST/GRADUATE

AFSC		FY80 $	FY82 $
34131	Instrument Training Specialist	3,675	4,513
34132	Defensive Systems Training Specialist	6,966	8,894
34133	Analog Flight Simulator Specialist	10,092	14,567
34134	Digital Flight Simulator Specialist	10,161	14,859
34135	Analog Nav Simulator Specialist	10,434	15,212
34136	Digital Nav Simulator Specialist	11,450	16,819

pay and allowances for leave accrued during training. They do not include training to attain an AFSC rating, on-the-job training, nor Type I training after reporting at the new duty station.

Government Documentation Costs

Based on cost data and educated estimates it costs three to five times more to buy the additional software documentation necessary for blue suit maintenance than commercial data. The variances can be explained by differences in commercial documentation provided by different companies. The percentages add up to large sums of money, over five million dollars on one program just for the basic documentation costs. If we add in the cost of training the seventy-five percent of first term ATD maintenance technicians that did not reenlist, an alternative solution becomes attractive.

COMMERCIAL DOCUMENTATION

Standards

There are no standards equivalent to those in the military to define what commercial documentation consists of, except some standardization accomplished through the computer industry (ANSII, etc.). Each company publishes individual standards and defines how their company will document computer programs. This is indirectly influenced by military standards for companies with a large share of the government market, although such compatability of standards is strictly voluntary. When a company publishes documentation standards it is up to that company to enforce those standards. The greatest difference between government and commercial standards on any given program is that government documentation is more consistent in format and includes additional documentation required based upon the support concept planned.

Commercial Acquisition

When a commercial ATD is procured, there are differences, compared to Air Force procurements, in the acquisition methods used as well as documentation standards. Where the Air Force requires a build-up of documentation from contract award to test, commercially only the functional design definition and math modeling details are documented during development. Informal reviews are held throughout the development process with design discussions recorded in formal minutes. At the end of the contract, CPS documentation that is delivered with the ATD is very similar to Air Force development documentation. Confidence of acceptable CPS documentation at the end of the program is based upon the advantage all commercial aircraft companies have over the government. That is, if the simulator contractor does not deliver what is required within cost and schedule, the commercial aircraft company can easily take their business elsewhere.

Commercial Maintenance

Commercial airline companies, i.e., those companies that train commercial aviation aircrews, (American, United, etc.), have a stable group of simulator operational support engineers and technicians that accomplish all software maintenance and modifications. This group has years of experience and is reasonably well paid; therefore, the companies do not have a major problem with turnover. Attrition is handled through employment of other experienced simulator engineers/technicians, often from military avenues or engineers from simulator manufacturers. Any shortages in the commercial documentation as delivered is usually updated and expanded as necessary.

COMPUTERIZATION OF DOCUMENTATION

What Is It?

There are many different ways documentation can be computerized, from digitally storing text and graphic images to writing programs to generate the documentation. All of these concepts have been created to save the large expense that software documentation adds to a program. Some computer vendors are developing a line of commercially available software that helps the user develop, test, document, and control application programs. Software houses and simulator companies have developed documenting programs or concepts which include the computerization of software document generation. Some examples of types of programs include utilizing program design languages to write all the narratives and descriptions; flow generators that can produce a diagram from functional block level down to a detailed flowchart; and, with a small modification, the documentation of the system hardware. Probably ninety to ninety-five percent of all software documentation or system documentation can be computerized to some degree. The remaining five to ten percent is of the type that is just more cost effective when accomplished manually.

Contractor Costs

If a contractor made the initial effort of developing a documentation system internally for use on future programs; he could reduce documentation costs approximately fifty percent. An extensive system could cut documentation costs to less than a dime a page, just implementing concepts that have been refined in the last few years, and are being discussed at many of the national computer conferences. The contractor costs would consist only of development costs of the software and any residual tasks for implementing the package on different machines, which could be minimal if portability were a design constraint.

Government Costs

To implement some type of computerization for documentation many questions need to be answered. Would it be more cost effective to standardize on one approach and require usage of that standard for all programs, or to provide a standard program and then require usage of that program? A study effort to define what the standard should be, with coordination between AFSC, AFLC, Navy, and users, would probably take one year. An alternate approach to reduce support costs would be to purchase a "documentation system" and digitally store all documentation to a specified format, compatible with the hardware system. Even this generates questions as to how many hardware systems would be bought and by whom? Each individual program could require computerization to the maximum degree technically feasible. Costs would be reduced by paying only licensing fees for previously developed programs. There are many alternatives and considerations, too many to name, from which the government can choose.

CONCLUSIONS

Documentation Standards

One of the largest continuing issues in the DOD is the standardization of military documentation requirements among the services. Each has its own CPS documentation standards, with the Army using the Navy 1644 standard frequently. In planning a reduction of documentation costs high priority should be the definition of a government standard, at least for training devices. Currently, an attempt is being made to define this standard. With this task accomplished, a comparison against commercial standards should be performed to define the documentation gap This comparison should identify the major penalties the government pays for normal maintenance concepts and where software documentation costs can be cut. Initial evaluation shows that there is no major differences between CPS documentation procured for an ATD with plans for CLS and a commercial ATD, except for enforcing contractor produced standards.

Logistics Support

The tie between the skills availabl to do software maintenance and support and software documentation is far too direct to gloss over. At the beginning of every program the user's operational and maintenance concept and staffing for the new ATD must be the primary input for documentation planning. If a CLS concept is being planned, then military-standard documentation is unnecessary. If an organic concept is being planned, commercial standards will surely fall short of what is needed to support the device. The step of tying user's plans with documentation requirements is one of the most important pre-Request for Proposal activities.

With the many new directions being received we may be forced into a CLS concept for all future ATDs. Although there is user resistance, CLS should force a reduction in government CPS documentation requirements, as well as its associated costs. Other ways of reducing government CPS documentation requirements are tied to the limited training and tour length of ATD maintenance technicians. By increasing the quality of training available, Type 1 and local university courses, extending tour lengths and overlapping transition periods when duty station changes are unavoidable the government can create a maintenance concept close to that of the major airlines. However, even these two concepts would not resolve the largest problem. Software documentation, even by commercial standards, if complete, is too costly.

Documentation Costs

Even is these two recommendations are implemented there is still a problem of high documentation costs. The area of greatest promise for cost savings in documentation is in the area of computerization. The computer products industry and computer resources institutes have recognized this in past years. Evidence of this can be seen by the prominence of written and presentation material at many computer conferences. The application of these concepts should directly impact the acquisition and life cycle support costs of software documentation for all government training devices. If applied carefully many existing problems should be resolved. The actual implementation of the techniques should be accomplished through validation against a minimum government documentation standard before contract award.

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APPLICATION OF MICROCOMPUTERS TO THE SIMULATOR "LINKAGE" PROBLEM

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ABSTRACT

Part of every modern cockpit simulator is an interface between the analog world of the cockpit and the digital world of the central simulation computer(s). This has traditionally been a complex system of analog/digital conversion circuitry commonly called the "linkage".

This linkage is expensive to build and requires modification to both the hardware and central computer software whenever changes are made to the cockpit instruments and controls. It also imposes a significant processing load on the simulation computer in that much polling of input and formatting of data are required. This paper describes a new approach that solves the problem by replacing the linkage with a microcomputer attached to each major instrument/control and small groups of minor instruments/controls. These instrument/control computers (ICC) functionally become part of the instrument/control and assume all simulation of that device that is independent of other activity. The ICCs pass data to the central computer and receive data from it only as necessary.

BACKGROUND

The control of an aircraft, and for that matter almost any machine, has traditionally been an analog function. That is, the pilot moves the main controls through an infinite number of positions and views his situation via indicators that can assume an infinite number of positions on the face of a dial. True, there are a number of important devices, such as switches and indicator lights, that are discrete in nature. And in modern cockpits the trend is to more and more discrete indicators, such as computer driven CRTs. Despite this trend the key controls and the key indicators are likely to remain analog devices.

In the early days of aircraft simulation the heart of the simulation itself was an analog device, in fact it was an analog computer. As the technology of digital computers came to the fore they began to take over the job of providing the simulation of flight. Although they were digital, or discrete, in nature they provided flexibility and cost advantages that far overshadowed their shortcomings. And it soon became apparent that if a series of discrete steps were small enough and quick enough they would appear to be continuous or analog in nature. So, the simulation problem has been taken over by the digital computer in virtually all cockpit simulators in recent years.

Although the digital computer handled the modeling problem quite well, the controls and instruments had to remain analog if they were to appear at all realistic. The problem of the digital simulation flight model on one hand and the analog cockpit on the other was handled by constructing an elaborate conversion mechanism. This converts analog signals flowing from the cockpit to digital values that can be digested by the computer, and translates digital values coming from the computer to analog voltage levels or synchro signals that drive the instruments. This mechanism is commonly known and is hereafter referred to in this paper as the "linkage" (Fig. 1).

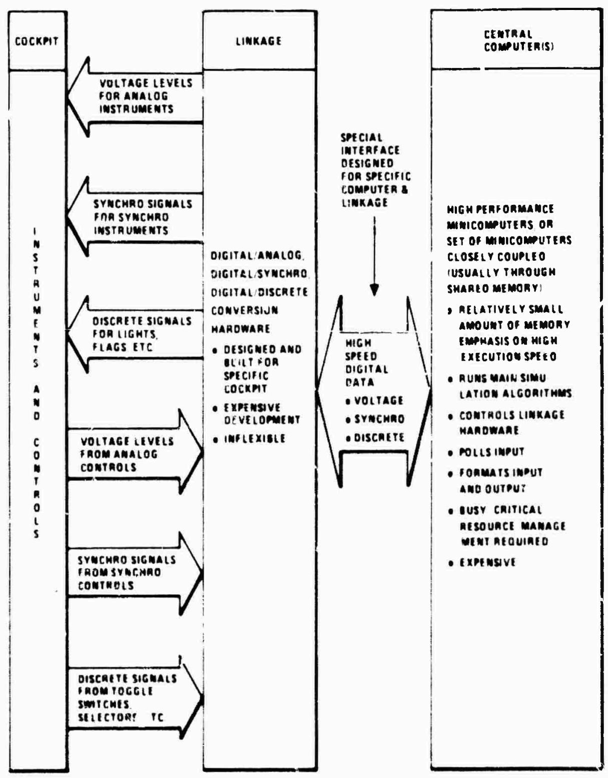

Figure 1. Conventional Simulator Architecture

This linkage, aside from its function, has many interesting characteristics. Most of them are undesirable. This paper outlines a new approach to the problem of communicating between the analog cockpit and the digital simulation computer that does away with the linkage and its associated problems.

THE PROBLEM

The linkage is expensive and inflexible. This inflexibility makes it even more expensive when modifications to the prototype aircraft must be reflected in the simulator.

Hardware

The linkage as found in most cockpit simulators is a set of hardware components, mostly A/D (Analog to Digital) and D/A (Digital to Analog) conversion circuitry. The linkage is built differently for each different aircraft that is being emulated. This reflects the fact that each different aircraft has a different set of instruments and controls, although many of the instruments and controls themselves may be exactly alike. For example, it is not at all uncommon for different aircraft to have the same make and model of altimeter. In the real aircraft this commonality has all sorts of advantages, such as reduced parts inventory, lower manufacturing costs, etc. But in the building of the linkage this cannot be taken advantage of because the linkage must match the set of instruments as a whole. That is, when instruments and controls are added, deleted, or modified in the prototype aircraft, the linkage must be modified to reflect this. While simulator manufacturers have designed the linkage hardware to be relatively easy to modify, this modification still entails considerable expense.

But this cockpit half of the linkage is but one side of the story. Another tale lies with the computer side of the linkage, where the problem is even more severe.

The hardware connection is a custom built interface between that particular linkage and that particular make/model of computer. If the computer is to be changed, for whatever reason, this interface also must be rebuilt or at least modified. Efforts have been made by the simulator manufacturers to design flexibility into the linkage to reduce the impact of changes in the computer, but again this is a compromise of necessity, not a solution.

Software

All the problems that have been mentioned thus far, however, deal with hardware changes and their impact. But an even more expensive, and less tractable, problem lies with the software associated with the linkage.

The information that flows between the computer and the linkage is not foot pounds of force on the yoke, nor is it feet of altitude, nor is it any of the units with which the simulation computer deals in its modeling calculations. The values that actually flow are voltage levels or synchro signals that indicate either the angular position of a control, or the angular position that an instrument needle is to assume. This implies that a lot of converting between formats is going on. And while many conversions are straight forward, most of them are not. Let us examine the typical case of a TACAN.

The TACAN is a relatively simple (in concept) navigation device found in most military aircraft that tells the person in the cockpit his bearing and distance from a fixed transmitter that he has tuned in. To accomplish this portion of the simulation in most systems, the following sequence of events occur at least five (typically 20) times a second:

> The simulation computer asks the linkage for the voltage value indicating the position of the TACAN channel selector switch.
>
> The linkage reads the voltage of the line associated with that switch, converts it to a binary value, and passes it to the computer.
>
> The computer converts the voltage to an angular position and associates that position with a channel number.
>
> Using that channel number as a reference, the computer looks up the geographic position of the transmitter associated with that channel in a table prestored in the program.
>
> The computer then looks at the present position and altitude of the aircraft and calculates the bearing and distance from the transmitter to the aircraft using simple trigonometry.
>
> The computer now converts the bearing value to a voltage that will cause the bearing instrument indicator to assume the angle associated with that bearing.
>
> The computer then converts the distance into four separate voltage values that represent indicator positions for tenths of miles, miles, tens of miles, and hundreds of miles.
>
> When all this is done the computer passes the voltage values to the linkage which converts the binary values to voltages and applies them to the lines attached to the TACAN bearing and distance indicators.
>
> The person in the cockpit knows where he is.

The sequence of events above illustrates several points.

Processing Load. The amount of processing done by the computer is a key factor in the design of any simulator. Usually the processing load is quite heavy. The above sequence illustrates what must be done to service one instrument for one cycle. In a typical simulator there are hundreds of instruments and controls, each must be serviced several times a second.

The computers selected to perform these functions are generally of relatively high capacity and are commensurately expensive. In many simulators several computers are linked together and share the load. Another effort generally made to meet the processing requirement is a specially designed software operating system. The operating system is either written completely by the simulator builder or is an extensive modification of one provided by the computer manufacturer. Either alternative is an expensive one. The application routines are written very carefully and exhaustively tested to insure that they not only function correctly but that they do not exceed their allotted memory space or execution time. Meeting time (or memory) constraints is generally considered the single most expensive factor in software costs.

In the example above, the amount of calculation actually concerned with the simulation itself was quite small. Most of the processing had to do with converting values and controlling the linkage. This is one example, but it is representative of what a simulation computer really does.

Modification Impact on Software. Whenever a modification is made to the cockpit, perhaps the addition or upgrade of an instrument, not only does the linkage have to be modified, as mentioned earlier, but the simulation program will have to be modified to handle the change. This is a very common occurrence and great pains are taken by the programmers to ensure that any new processing involved does not exceed any critical memory or timing constraints.

THE SOLUTION

Suppose now we could eliminate the linkage as described herein. Along with this we could eliminate the requirement to control it and the requirement to constantly reformat the data flowing between the computer and the linkage. We could then concentrate solely on the true simulation functions. This would reduce the total processing load by several factors and with this reduction one can suddenly:

- Reduce the number of central computers in the simulator.
- Utilize less expensive computers.
- Use standard operating systems.
- Simplify development of application software.
- Reduce the cost of building and maintaining a simulator.

The rest of this paper explores a method of doing just that.

The Concept

Put simply, it is to attach and devote an entire computer to each major instrument, each major control, and each group of minor instruments and controls in the cockpit. Such a computer would directly move the indicators on an analog instrument based on digital data passed to it from a central simulation computer. Another would constantly observe the position of an analog control and periodically send information concerning it to the central computer.

Each of these computers would be complete in itself, independent of the others, and dependent on the central computer only for data. Data passed between the computers would be, of course, in digital format and expressed in units that the simulation program naturally deals with.

The computers coupled to the instruments and controls, henceforth referred to as ICCs (Instrument/Control Computers) must be complete computers, with a central processing unit (CPU), memory and I/O (input/output) capabilities. But they will not be the large, cabinet mounted devices, that one usually associates with computers. They will, with few exceptions, be contained on a single chip and they will be identical. The difference will be the program within them. A subsequent section provides more detail on the characteristics of these computers and the method used to communicate between them.

ICCs driving instruments will primarily format and convert the data as received from the central computer and directs its output to the instrument. They may also provide some of the more rudimentary simulation. For example, the ICC driving a heading indicator may provide a dampening or coasting effect. This would lower the number of updates required by the central computer but would maintain smoothness and accuracy. Another such situation would be the ICC monitoring the control yoke/stick. In present simulator design the central computer periodically polls the control and receives back a set of values indicating its present position. An ICC would monitor the position constantly and periodically report back not only its position, but could easily determine and report the amount of change, direction, and velocity. These values are now computed by the central computer.

An even higher level of simulation could be handled by the ICC provided that the function to be simulated is relatively isolated. Take again the example of the TACAN mentioned earlier. Almost the entire simulation problem for that device could be handled by the ICC. That ICC could monitor the channel selector input, determine the position and characteristics of the transmitter from a table stored in its own memory, compute bearing and range, and drive the indicators. The only requirement of the central computer in this case would be to periodically transmit the aircraft's position and altitude to the ICC.

Although this paper is primarily concerned with analog functions, it should be mentioned that this concept is just as applicable to discrete functions. That is, an ICC can handle switch inputs and discrete outputs as well it can analog values. The major benefit in this regard is that the ICC can poll the discrete devices for input and only report changes to the central computer, thereby relieving the central computer of a time consuming task.

Advantages

There are many.

Lower Processing Load. The main one, already treated, is to simplify and reduce the processing required of the main computer. This will not be dwelt upon further except to say that the processing load will be a small fraction of what it is now.

Modularity. Another important benefit revolves around the concept of modularity. For purposes of this discussion let us define modularity as that quality that permits us to add, delete, or modify pieces of a system without effecting other pieces, or the system as a whole. Perfect modularity is never achieved in any system that has interrelated components, but modularity is generally achieved to some degree.

The benefits of modularity for a system such as a simulator reside on two areas. The first is cost of modification. If one can add, change, or delete a component without worrying about what effect such a change will have on other parts, the cost will be much less than it might otherwise be. This is generally accepted and will not be elaborated.

The second major benefit of strong modularity is simpler system integration. The more modularity that the designer can achieve the less concern he will have with interference, timing constraints, resource conflicts, and the like. Also the system implementor will have to spend less time testing the system to verify with confidence that it performs as intended. All of this translates directly into lower total costs. This author's primary professional activity for the last ten years has been in the design and implementation of various large, real-time, process control systems. It has been his experience that approximately one third to one half of the total system development effort has been in the integration and testing phase.

If one can devote an entire computer to one instrument or control, many integration problems are not just solved, they simply do not exist. For example, if one can program one of these computers to drive the TACAN display, one can test the function by sending the present aircraft position and altitude to it and observe the display. It makes no difference whether the program was written by a novice or an experienced programmer. It makes no difference what the make or model of the central computer is. The system designer does not have to be concerned about how much of the total processing time or the total memory that the TACAN simulation routines will consume. In fact, it makes no difference what aircraft is being simulated. It will function the same in any cockpit simulator that has that particular TACAN.

Also, if the TACAN display in the simulator is changed for any reason, only the program in the ICC driving it need be replaced. Such changing will have absolutely no effect on the central computer or its program. In a later section it will be shown that in some cases it will also be possible to add instruments to the cockpit without modifying the central computer or its program.

A few words should be said about the capacity and power of these computers. The ICCs as envisioned here have modest capabilities compared to those driving most simulators today. However, they are quite comparable in power to those available just a few years ago. And when one considers that they will be required to handle just one or a few functions, their speed and memory capacities will be more than adequate. And although it is envisioned that all ICCs will be alike, they need not be. A more powerful version could be inserted to handle a particular cockpit device. Its only requirement is that it observe the same communications protocol.

Communication.

Several references have been made to passing data between the ICCs and the central computer. Without a consistent and well thought out convention in this area all the benefits mentioned above will not accrue.

There are several ways that the ICCs and the central computer can be linked. The one mentioned here appears the least costly and easiest to implement.

The method presented here is simply the serial linking (daisy chain) of all the ICCs on a single line from the central computer (figure 2). The electrical standard is a subset of the common commercial RS-232. The ICCs are arranged in a loop network, where the input line of an ICC is connected to the output line of the upstream ICC. The input line of the first ICC is connected to the transmit line of the central computer's serial port and the output line of the last ICC is connected to the receive line of the port. Salient features of this scheme are:

Data would remain in binary format, preferably in the same notation used by the central computer's main simulation program.

Data would be packaged in messages. Each message would have a header containing an address, message identifier, length indicator; the data of interest; and a trailer containing a simple checksum or other error checking mechanism.

Messages from the central computer to the ICCs would be either of a broadcast nature (with data of interest to more than one ICC) or would be addressed to a particular ICC. The address of the ICC would be its position on the chain. If an instrument and its associated ICC require only broadcast data, it could be added to the cockpit without modification of the central computer.

In this scheme the central computer would initially transmit a message to the first ICC on the chain. The ICC would immediately retransmit it to the next station downstream, no matter what message it is or for whom it is intended. Each of the ICCs would do this with every message no matter what position it held in the chain. As part of the retransmission an ICC would decrement the address. After the retransmission was complete, the ICC would look at the address. If the address value is zero, the ICC would know that the message was intended for it and would act upon it.

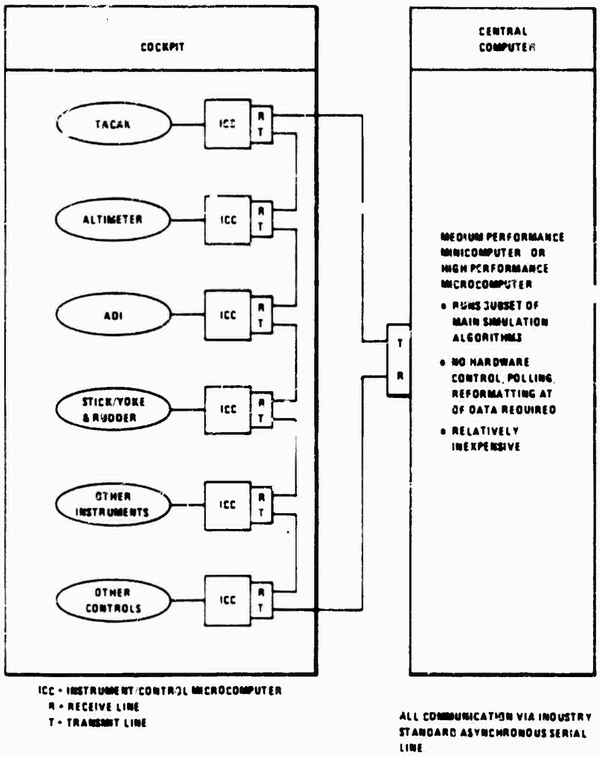

Figure 2. Multi-Microcomputer Simulator Architecture

The retransmitted messages would eventually get back to the central computer which could be compare them with what had been sent. This is the most foolproof of error checking schemes. This might be useful in some very critical applications, but the communication environment inside a simulator is quite benign and communication errors are not likely to be a problem.

ICCs wishing to originate messages on this net would simply transmit them whenever they are not retransmitting other messages. The initial address word in this case would be zero. By the time the message reached the central computer the address slot would have a negative value corresponding to the ICC's position on the net. This technique eliminates the complication of a master ICC on the net to arbitrate requests.

Part of the communications software package in each ICC would be a watch dog timer that would originate a trouble message if it had not received a message within a specified period of time. Whenever such a message were received by the central computer, it would know and could inform an operator that an ICC had failed, and from the address value of the message could determine which ICC had failed (it is the one upstream from the ICC that reported it).

This communications scheme has several interesting characteristics:

Simplicity. It uses the most common and universal electrical protocol. It is familiar to most programmers and engineers and is supported by virtually all existing operating systems.

Speed/Capacity. As networks generally go, this method is not conducive to moving great amounts of data quickly. But it should be adequate for this application. To demonstrate this let us look at what a typical communications load might be. Let us assume that:

> The transmission rate is 188 kilobaud. The ICCs as described later can obtain this rate. With 10 bits per character we have a character rate of 18,800 characters/second.
>
> The central computer, running the main flight dynamics package, broadcasts a message containing key data such as current altitude, speed, heading, pitch angle, roll angle, vertical speed, angle of attack, and X-Y position five times a second. Each of these values can be held within 32 bits. The entire data portion of the message would then be 288 characters. With header and trailer characters let's assume this message to be 300 characters long.
>
> The ICC monitoring the yoke/stick and rudder pedals reports position, delta position, and velocity of each of these controls 20 times a second. Each of these values can be held in 32 bits. The data portion of this message would then be 192 characters long. With the same header and trailer the entire message would use 204 characters.
>
> The remaining traffic would reflect asynchronous events such as the pilot flipping switches or the central computer lighting various indicators. Let's assume that this information requires 100 characters/second.

The total communications load would then be:

$$(300*5) + (204*20) + 100 = 5680 \text{ chars/second.}$$

At first glance it may appear that the time required to retransmit a message will cause significant delays. If it takes 100 microseconds to relay a word in each ICC, the first word of a message will reach the 10th ICC in one millisecond. This is not significant in light of the basic transmission rate.

A multi-drop network based on a high speed bus, such as Xerox's Ethernet, could also be used. There would be no retransmission delay and the capacity would be higher as would the cost of hardware and software needed to support it. From the viewpoint of required capabilities, such an effort does not appear to be justified.

Reliability. Stringing all the ICCs together in serial fashion has the inherent drawback that the failure of one of them will effect the whole system. Generally system designers avoid such situations. But the simplicity of the ICCs will provide high inherent reliability in each of them, the high modularity of the system will make them easy to replace, and the failure reporting mechanism mentioned above will pinpoint the failed unit. Based on this the complication and expense of a less vulnerable scheme does not appear to be warranted.

The Computer.

In order to make this whole concept viable the computer on which the ICC is based must be very small, very reliable, and very cheap. The historic trend in computer development has been in this direction. But only recently has development come to the point where it is viable to devote an entire computer to each instrument.

The forerunner to the computer to be used here is the microprocessor. This had a very significant impact on the industry and in the world in general. The most notable result is the home/hobby computer. Capable as they were, microprocessors usually consisted of a CPU only and required significant support circuitry in the form of clock chips, I/O chips, interrupt chips, memory and the like. Now development has reached the point where all of these functions are combined on a single low-cost chip.

These chips are just now hitting the market. Zilog, Inc. offers the Z8, Intel has the MCS-51 series of chips, and Texas Instruments will be offering such a chip sometime in 1982. Of the two currently available, the Intel offering is newer and has more of the capabilities required for this application. Some of its important characteristics are indicated below:

- Four KB(kilobytes) of on-chip memory. 128KB addressable memory using auxiliary chips.
- Single 5-volt power source required.
- Five interrupt sources available with automatic interrupt vectoring. Two level interrupt priority.
- Two interval counter/timers.
- All timer, interrupt support functions, etc on board the chip.
- Built-in serial input/output line 30 discrete input/output lines.
- Very powerful processor that includes:
  - Hardware multiply/divide (four microseconds).
  - Four sets of eight general purpose registers.
  - Stack instructions.
  - Multiple addressing modes.
  - Boolean subprocessor for bit manipulation.
- Less than $25 in single quantities.

FUTURE EXPANSION

This concept can be quite easily expanded to include more than just the devices in the cockpit. Visual systems, motion platforms, and instructor/operator stations (IOS) could be included on the same loop (fig. 3) or a separate loop. This would establish a de facto standard interface for these components to which manufacturers of these major subsystems could design.

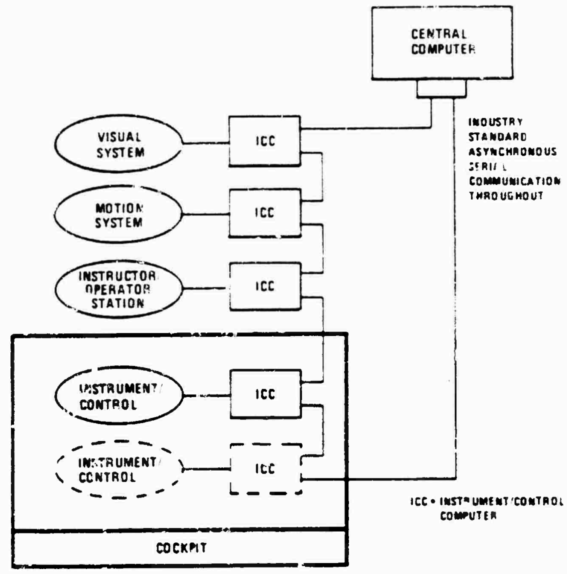

Figure 3. Modular Cockpit Simulator Architecture

There is a movement in the simulator world to expand the instructional features of simulators to include scenario generation, performance evaluation, graphic displays, briefing/debriefing, replay, record keeping, and the like. Such facilities usually require separate computer systems. An interface mechanism based on the concept outlined in this paper would permit the addition of these facilities without serious impact on the rest of the system. That is, it would be possible to exchange simple IOSs with sophisticated ones or vice versa, depending on the role of the simulator, features desired, availability of funds, etc.

SUMMARY

Once an ICC is built, programmed and attached to an instrument, it is a part of that instrument forever. It can be used without modification in any simulator. On the other hand a modified instrument/ICC can replace an existing one without effecting the central computer and its software.

The strong modularity inherent in this approach simplifies system design, eases system integration, and reduces required testing. The simulation and other processing performed by the ICCs will greatly reduce the processing load on the central simulation computer.

The ability to interface dissimilar subsystems will permit the system designer to pick and choose major components from different manufacturers to make up a training system tailored to its functional role.

ABOUT THE AUTHOR

Mr. Seidensticker is a member of the technical staff of the Advanced Systems Department of the Tactical and Training Systems Division of Logicon. His primary work for the past several years has been in the design and development of advanced instructor/operator stations for cockpit simulators. He holds a liberal arts undergraduate degree and a Master of Science in Systems Management from the University of Southern California.

EVALUATION OF COMPUTER CONFIGURATIONS FOR SIMULATION

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ABSTRACT

This paper provides an evaluation of computer configurations that might be applied to a single large simulator or a complex of simulators. The analysis indicates that minicomputers or the recently introduced super minicomputers offer the best approach to implementation of most simulators. The very large computer designed for high throughput in a multiprogramming environment is not cost effective for the simulator application, and the yet unsolved problems in partitioning the simulator computations for use in a distributed microprocessor network outweigh the saving in hardware cost. More important than the results of this study is the method of analysis developed for evaluation of computer configurations in simulator systems. The procedure presented can be used to address other configurations and different values of such variables as reliability, mean time to repair and cost. The method is recommended for use in evaluating computer implementation for specific simulator procurements.

INTRODUCTION

The need for a broad analysis of computer architecture is the result of procurement under Office of Management and Budget Circular A-109. This procurement procedure gives vendors a wider latitude in proposing innovative systems. At the same time, it places upon the government a requirement to evaluate these proposals to determine which vendor's approach is best. The purpose of this study is to provide reference material and guidelines in one of the critical areas (computer systems) to be evaluated. Although the specifics used in the example are taken from a specific trainer, the approach is applicable to flight trainers in general and the ideas are related to any kind of trainer.

This study addresses the problem of what computer configuration should be used in the computer complex for a multiple-cockpit flight trainer. It considers the characteristics of each generic class of computers, with no attempt made to assess the advantages and disadvantages of the manufacturers' products within the class. Computer architectures for performing the computation and control functions required are evaluated to determine the advantages and disadvantages of each.

Cockpit Configuration

The baseline cockpit configuration selected for the analysis is the representative simulator suite described by the VTXTS technical team [1]. This training suite consists of six Cockpit Procedures Trainers (CPT'S), fifteen Operational Flight Trainers (OFT'S) without visual systems, nine OFT'S with visual systems, and six Air Combat Maneuvering Trainers (ACMT'S). The total training suite is divided into three identical cockpit arrangements. Figure 1 shows one of these divisions with its computer complex.

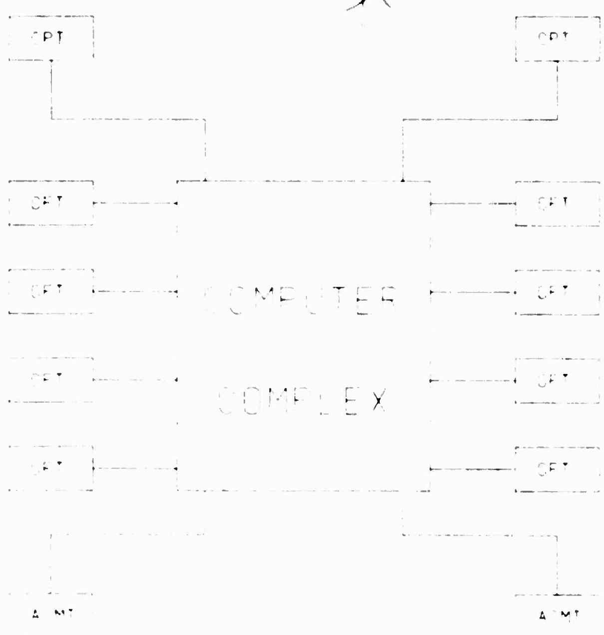

Figure 1. VTXTS Cockpit Arrangement

COMPUTER PERFORMANCE

Assessing a computer system's ability to solve a problem is a critical part of evaluating various computer architectures. The method selected is to specify the problem to be solved by the computer complex in terms of computer performance, number of instructions to be executed during a given time, and storage requirements.

The capability of a given computer to solve the problem is based upon an Average Instruction Execution Time (AIET), a figure of merit determined by the hardware instruction execution times of the instructions weighted by a per cent use factor. Two sets of weighting factors were used, one for Operational Flight Trainers (OFT's) and one for Weapon System Trainers (WST's), based upon a composite of actual instruction counts from several existing OFT'S and WST's.

Table 1 shows AIET's for various computer systems for the two instruction mixes. Results for the minicomputers (Digital PDP 11/70, Systems SEL 32/77, and Perkin-Elmer PE 3240) are taken from a report [2]. The performance of the other computers is estimated by comparing their speed to the speed

TABLE 1. AVERAGE INSTRUCTION EXECUTION TIME

COMPUTER	AVERAGE INSTRUCTION EXECUTION TIME (MICROSECONDS)	
	[illegible] MIX	[illegible] MIX
Digital PDP [illegible]	[illegible]	[illegible]
Systems SEL 32/[illegible]	[illegible]	[illegible]
Systems SEL 32/[illegible]	[illegible]	[illegible]
Perkin-Elmer PE [illegible]	[illegible]	[illegible]
Amdahl 470/V7	[illegible]	[illegible]
Motorola MC68000	[illegible]	[illegible]
Zilog Z8000	[illegible]	[illegible]
Intel 8086	[illegible]	[illegible]

of the minicomputers for a subset of the total instruction repertoire. The Amdahl computer performance is estimated from the ratio of ADD and MULTIPLY instruction execution times on the Amdahl 470V/7 [3] compared to those of the minicomputers. The performance of the microcomputers (Motorola MC68000, Zilog Z8000, and Intel 8086) is estimated by comparing the instruction execution speeds given in a comparison of the microprocessors [4] to the minicomputer instruction execution speeds. Capability of the newest entry (System 32/87) is estimated from the ratio of performance on the British Whetstone benchmark program for the Model 32/87 and the Model 32/77 given in the manufacturer's data sheet.

Computer Classes

The computers considered have been divided into four classes (Large Computer, Minicomputer, Minicomputer, and Microcomputer) an appropriate execution speed has been assigned each class. The computers are divided into classes, because the purpose of this study is to determine computer configurations in terms of these classes and not to distinguish between the products of various manufacturers within a class. The AIET's shown in Table 1 were converted into the nominal instruction execution speeds for each class shown in Table 2.

The distinction between the Large Computer and the Super Minicomputer requires some explanation. Although the examples presented differ in computation speed, this is not the criterion that distinguishes the two. The super minicomputer is an improved 32-bit minicomputer with an architecture which results in 3 MIPS or greater speed in executing instructions. The large computer is one designed for use in multi-user environments, both data processing and scientific computation. It has a high-speed arithmetic capability, but it also has features such as multiple I/O channels and sophisticated operating systems designed for the multiprogramming environment. Normally, the operating system for the large computer is not designed for time critical tasks in the frame considered in real-time flight simulators.

TABLE 2. COMPUTER CAPABILITIES USED IN ANALYSIS

COMPUTER TYPE	CAPABILITY (1000 Instructions Second)
Large Computer	16,000
Minicomputer	900
Super minicomputer	5,000
Microcomputer	200

STORAGE AND PROCESSING REQUIREMENTS

The storage and processing requirements shown in Table 3 were derived from available data on trainers in the Navy inventory. This table provides a summary of the minimum and maximum storage and processing requirements for each type of simulator and shows the processing and storage requirements assumed for this analysis. The complete data from which this summary is made are available in a report [5].

TABLE 3. SUMMARY OF PROCESSING AND STORAGE REQUIREMENTS

DESCRIPTION	SIMULATOR			
	CPT	OFT	[illegible]	ACMT
Processing Requirements: 1000 Instruct. Per Sec.				
Minimum	[illegible]	[illegible]	[illegible]	[illegible]
Maximum	---	[illegible]	[illegible]	[illegible]
Value Used in Analysis	[illegible]	[illegible]	[illegible]	[illegible]
Storage Requirements: [illegible]-Bit words				
Minimum	[illegible]	[illegible]	[illegible]	[illegible]
Maximum	[illegible]	[illegible]	[illegible]	[illegible]
Value Used in Analysis	[illegible]	[illegible]	[illegible]	[illegible]

COMPUTER CONFIGURATIONS

The computer system for a CPT is usually a single computer/processor configuration with private memory, peripheral equipment, mass storage memory and cockpit input-output conversion equipment (linkage). The computer sytem of a modern OFT or ACMT is usually a multiprocessor configuration with private memory, shared or common memory, peripheral equipment, mass storage memory, and cockpit input/output data conversion equipment. This system is typical of the conventional master-slave computer system configuration [6,7].

For a complex of trainers, the designer has a much wider choice of computer arrangements. The configurations considered range from a single large computer to a distributed system of 38 microcomputers. In a multiprocessor configuration, one processor is designed as the master unit which controls the training system. The master processor usually contains the software for instructor station functions, data recording/playback, simulator modes of operation. The slave processors contain the software for flight, engines, accessories, communications/navigation, weapons and all the other simulation functions.

Minicomputers

Two different minicomputer configurations are considered in this analysis. The simpler in terms of implementation is shown in Figure 2. This is an attempt to use a one-on-one match of computer to

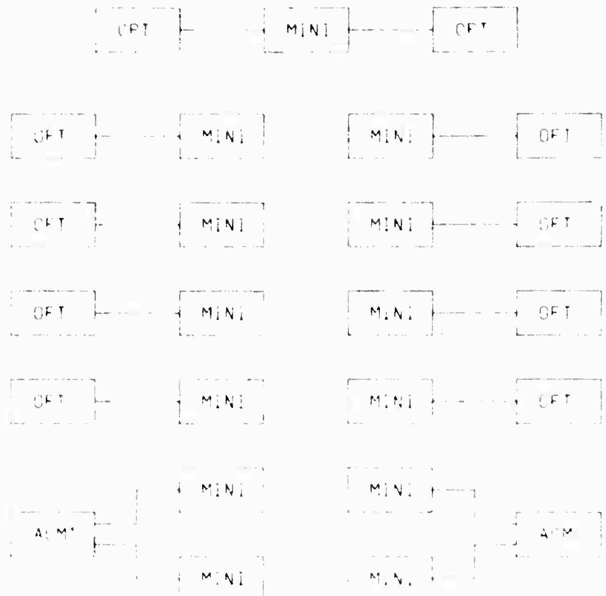

Figure 2. Dedicated Minicomputer Systems

cockpit, modified to take care of gross mismatches in the simulator requirements and the computer capabilities. For the OFT's the match in capabilities and requirements allows the one-on-one arrangement. Since the CPT's use less than half of the capability of a single computer, one computer is used to drive two CPT's. The ACMT implementation introduces the opposite problem. Since a single computer does not have enough capability to perform the computations required, two computers must be used for each ACMT.

The alternative to a one-on-one arrangement is to use multiple computers to drive multiple cockpits. Figure 3 shows this concept applied to the entire complex of cockpits. This results in considerable saving in the number of computers required, reducing the 13-computer configuration shown in Figure 2 to only 8 computers. The disadvantage of this approach is an increase in software cost and complexity.

Figure 3. Shared Minicomputers

Super Minicomputers

Figure 4 shows a Super-Minicomputer configuration for the cockpit complex. Use of Super Minicomputers is attractive because, unlike the large computers described next, the Super Minicomputer provides a greater increase in processing capability than the increase in cost. The reason for this is that the major additional cost is in the high-speed arithmetic element rather than I/O devices or sophisticated hardware for improving the computer's performance in a multiuser environment.

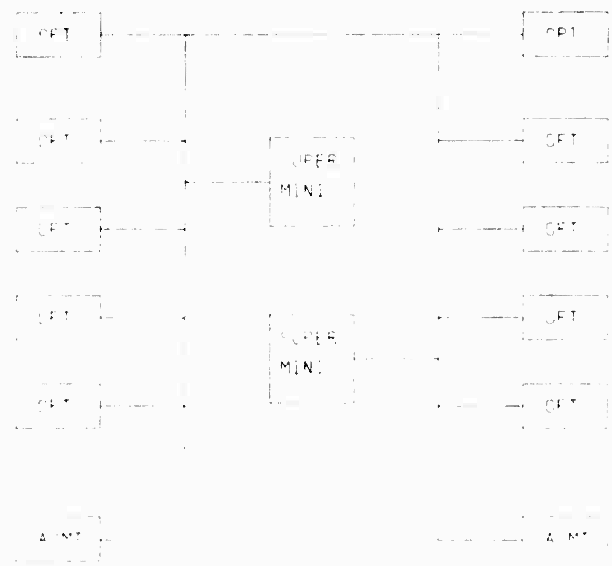

Figure 4. Super Minicomputer Configuration

Large Computers

A single large computer can be used to perform the required computations for the whole cockpit complex. The major effect of using a single large computer is a decrease in total availability of the system.

A major drawback in using a large computer for the simulator complex is its cost. In general, the cost of a larger, faster computer grows more than linearly (i.e., a computer ten times as fast usually costs more than ten times as much). For example, the Amdahl 470V/7 costs about 25 times the price of a Perkin-Elmer 3240 [3] but has only a 20 to 1 advantage in computation speed. Use of a large computer cannot be discarded in all cases, but this type of architecture does not seem to provide any advantage in the the present application.

Microcomputers

A microcomputer configuration for the cockpit complex is shown in Figure 5. Use of multiple microprocessors offers saving in hardware cost over the use of larger computers. Summer and Wyndle [8] estimate the cost of a microprocessor OFT to be little more than one-half the cost of an OFT implemented with minicomputers. Their analysis of life cycle costs shows a similar saving in software and maintenance costs. Indeed, the multiple microcomputer network provides a number of advantages over other approaches. However, these

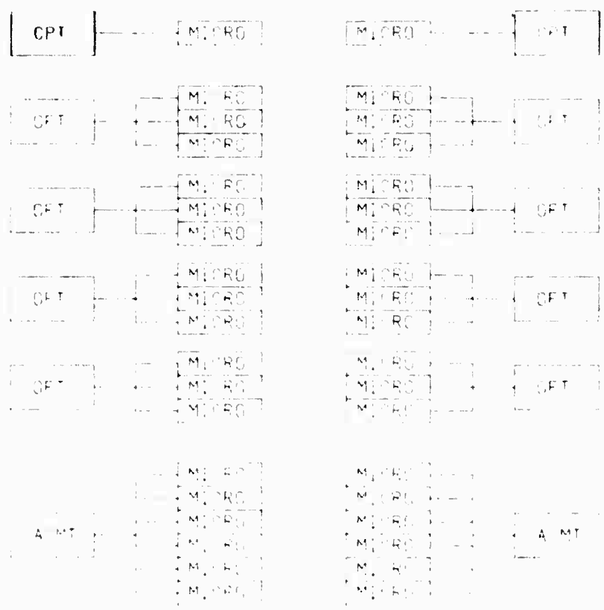

Figure 5. Dedicated Microcomputer Systems

advantages are outweighed by its one disadvantage--such a system has not yet been developed. Use of multiple microcomputers is likely to result in high development costs and an associated high risk in added cost and in schedule slippage.

The development cost and high risk of a microcomputer system result from problems that must be solved in order to use multiple microcomputers effectively. Three major steps must be taken in order to take advantage of the inherent parallelism that exists in many applications.

a. Partitioning of the problem into disjoint tasks.

b. Provision for centralized control.

c. Development of a run-time structure which provides for the passing of system parameters between tasks and/or processors while preserving precedence.

NAVTRAEQUIPCEN has conducted an active research program in this area since 1974 [9,10]. Implementation problems which have been solved include:

a. The development and demonstration of a control algorithm for "N" microcomputers embodied in hardware, firmware and software. This control algorithm is identical in each microcomputer and functions as an applications task manager (ATM) for distributed control.

b. The development and demonstration of a distributed cache concept whereby the address space of a shared (common) memory is distributed among each applications processor. Data and parameters to be passed to various processors from other processors are broadcast globally on the system data bus but are read locally in each processor in a parallel manner. This significantly reduces the system data bus bandwidth requirements and the likelihood of bus contention.

c. The processing frame scheduling (unique to real-time sampled data processing) is carried out by the control processor. Groups of microcomputers are scheduled according to the processing required in a given frame time. All interprocessor communications are controlled by the ATM which is stored in a PROM.

The microcomputer configuration is interesting for future applications, but the research program has not yet provided the answers needed to use this approach on a simulator procurement. This configuration is included in the evaluation with the high risk of such an approach made part of the analysis.

EVALUATION OF CONFIGURATIONS

Availability

The inherent availability of a system is the probability that the system, when properly used and adequately maintained, will operate satisfactorily at any point in time. This definition excludes preventative maintenance actions, logistics supply time and administrative downtime. The inherent availability is expressed as:

$$A_i = \frac{MTBF}{MTBF + MTTR}$$

where MTBF is the mean time between failures for the system considered, and MTTR is the mean time to repair a failure.

Availability of the simulators for training is a major consideration in the system design. For this analysis each simulator is assumed to consist of a cockpit, an instructor station and that portion of the total computer system required to make it work. The reliability and maintainability numbers used in this analysis are given in Table 4. The inherent availability is shown in Table 5.

Maintenance

Maintenance of the computer system includes both hardware and software. At the level of this analysis, the distinction between contract and in-house support in either area cannot be made. Such a determination will require further study after a computer configuration is determined. A hardware cost estimate of one per cent of the initial cost of the equipment per month is used for this analysis. This estimate is derived from a study of maintenance contract charges for several vendors.

An exception is made in the case of the microprocessor system, for which vendor maintenance is not available. The cost of maintenance for the microcomputer system (except for the peripherals) is estimated at two per cent of the hardware cost. Peripheral maintenance is estimated at one per cent, just as in the other configurations.

The cost of this software support is estimated to be ten per cent of the initial software cost per

TABLE 4. RELIABILITY AND MAINTAINABILITY VALUES USED IN ANALYSIS

ELEMENT	FAILURES PER 1000 HOURS	MTBF (Hours)	MTTR (Hours)
Cockpit	2	500	1
Instructor Station	.5	2,000	1
Large Computer	20	50	2
Large Computer (with redundancy)	20	50	.25
Super Minicomputer	8	125	2
Super Minicoputer (with redundancy	8	125	.25
Minicomputer	4	250	1.50
Minicomputer (with redundancy)	4	250	.25
Microcomputer	1	1000	.5

TABLE 5. SIMULATOR AVAILABILITY

CONFIGURATION	AVAILABILITY		
	CPT	OFT	ACMT
Separate Computer Systems Each Cockpit	.9915	.9915	.9855
Separate Computer System Each Cockpit (w Redun)	.9965	.9965	.9955
Shared Computers with Min. Hardware	.9915	.9915	.9855
Shared Computers with Min. Hardware (with redundancy)	.9965	.9965	.9955
Super Mini-Computers	.9815	.9815	.9815
Super Mini-Computers with redundancy	[illegible]	.9955	[illegible]
Single Large Computer	[illegible]	[illegible]	[illegible]
Single Large Computer with redundancy	[illegible]	[illegible]	[illegible]
Microcomputers	[illegible]	[illegible]	[illegible]

year. This estimate is based loosely on the work of Putnam and Wolverton [11], which finds that support costs are 150 per cent of the acquisition cost for most software systems. For the simulator application, which should require less support than a data processing application, this cost factor is estimated to be less than the normal amount. Therefore, the software estimate used in this analysis is 100 per cent of the acquisition cost, or ten per cent of the acquisition cost per year.

Expandability

Expandability will be considered in three parts: (1) an increase in the capability of each individual simulator, (2) the addition of one complete cockpit to the system, and (3) the addition of two cockpits to the system.

Minicomputers. A reasonable increase in capability for each cockpit requires no change in the minicomputer implementations considered, because a spare capability is built into the computer requirements. An increase that exceeds the spare capability provided presents a severe problem. In the implementation shown in Figure 2, such an increase can lead to doubling the number of computers required. Those configurations that use multiple computers to drive multiple cockpits are much less sensitive to increases in requirements. In a multiple computer configuration, the entire spare capacity of the computer system can be used for a single change. If a change does require addition of a computer, the entire spare capacity added is available to all simulators as needed.

An increase in the number of cockpits is a simple change for the configuration shown in Figure 2. An added cockpit requires the addition of a new cockpit and an associated computer, an addition that is totally independent of the existing system. Addition of another cockpit is the same. For multiple computer configurations, the addition of a cockpit can be achieved by adding another computer to the network and making the appropriate programming changes. The major difference is that the total system software must change and that some lost time will be encountered in introducing a new system on a shared computer complex.

Large Computer. For the system using a single large computer, any addition up to the capacity of the computer is a relatively simple change. Since all spare capacity resides in one computer, a change may make use of the entire spare capability. When an addition exceeds the capacity of the computer, a serious problem is encountered. A choice must be made to add a second very expensive large computer or to add a stand-alone minicomputer. The use of a minicomputer may reduce the cost of the addition, but it adds to the maintenance problem by introducing a different type of computer with associated problems in spare parts and in training requirements. It complicates the software maintenance problem, even though the computer program is written in a high-level language. The software personnel must learn a new operating system and I/O handlers and the idiosyncrasies of the high-level language compiler for the new machine.

Super-Minicomputer. The expandability for the super-minicomputer configuration is very much like the situation with a large computer. A single computer handles several cockpits, making an addition in the computation load up to half the spare capacity of the system relatively easy. However, any expansion greater than that requires addition of new, relatively large computer.

Microprocessor. The microcomputer implementation offers the easiest expansion. The modular nature of the system allows any change to be made with a minimum of additional computers.

Life Cycle Cost

The life cycle cost model considers only those elements associated with the computer configuration. The items used in the simplified life cycle cost model are derived below.

Hardware Cost. Hardware costs used in the cost model are shown in Table 6. The computer prices are based upon nominal prices for each class of computer with memory and peripherals. These costs are based on list prices contained in a standard reference [3] and on information supplied by various vendors. Costs for an actual system might vary considerably because of Original Equipment Manufacturer (OEM) agreements that a simulator

TABLE 6. HARDWARE COST ESTIMATES USED IN ANALYSIS

COMPUTER TYPE	COST (1000'S)
Microcomputer	4
Minicomputer	140
Super minicomputer	350
Large Computer	2,350
Memory Bank	50

simulator vendor might have with the computer manufacturer. However, the costs are considered reasonable for the purpose of comparing the different configurations.

Table 7 shows the life cycle cost for each major item for each configuration considered. The hardware cost is taken directly from Table 6, with the following exceptions:

a. Cost for a second large computer is reduced by 20 per cent, because a complete set of peripherals is not required.

b. Cost of a set of peripherals is added to each microcomputer system. This cost is estimated to be $40K per cockpit.

Software Costs. Software costs are more difficult to estimate. The basic software cost is estimated by determining the program size and applying a cost factor based only on the number of instructions. The software cost for each different configuration is determined by modifying this basic software cost to account for any additional complexity in the software due to partitioning the program to be executed so that it can be run in a multiprocessor environment.

The following assumptions are made in determining the basic software cost for each type of trainer:

a. FORTRAN is the source language.

b. The FORTRAN expansion ratio is 4 machine instructions/FORTRAN statement.

c. Programmers will program at a rate of 2000 statements/year including design, code, and checkout.

d. Labor costs are $90,000 per man-year.

e. A CPT has a 24K word program or 6K FORTRAN statements.

f. An OFT has a 64K word program or 16K FORTRAN statements.

g. An ACMT has a 96K word program or 24K FORTRAN statements.

The basic software cost computed using these assumptions is given in Table 8. This gives the cost of programming for each type of simulator when the program is executed entirely within one computer.

Many of the configurations considered require some partitioning of the problem to allow it to be solved in a multiprocessor system. The following assumptions are made about the increase in software complexity due to partitioning.

TABLE 7. LIFE CYCLE COST OF VARIOUS COMPUTER CONFIGURATIONS

CONFIGURATION	COST ($1000)					
	HARDWARE ACQUISITION	SOFTWARE ACQUISITION	ANNUAL SOFTWARE SUPPORT	ANNUAL HARDWARE MAINT.	10 YEAR TOTAL 3 SYSTEMS	20 YEAR TOTAL 3 SYSTEMS
Separate Computer Systems Each Cockpit	1,920	2,297	230	230	17,266	26,475
Separate Computer System Each Cockpit (W/Redun)	2,060	2,297	230	247	18,190	27,903
Shared Computers with Min. Hardware	1,370	2,545	255	164	14,132	21,609
Shared Computers with Min. Hardware (with redundancy)	1,510	2,545	255	181	15,056	23,307
Separate Computers for All	700	2,070	207	84	8,760	13,350
Separate Computers for All (with redundancy)	1,050	2,070	207	126	11,070	16,920
Single Large Computer	2,300	2,070	207	276	19,320	29,670
Single Large Computer (with redundancy)	4,140	2,070	207	497	31,464	43,438
Microcomputers	592	3,737	374	89	11,928	18,344

TABLE 8. SOFTWARE COST ESTIMATES USED IN ANALYSIS

TYPE	EFFORT	COST (1000'S)
CPT	3 MY	270
OFT	8 MY	720
ACMT	12 MY	1080

a. The program size increases by ten percent for each separate computer system over which the simulator software is distributed.

b. The software development effort for a partitioned program grows as the square of the increase in program size.

The first assumption is an estimate of the growth in program size due to increased need for control and communication between program modules. The second is based upon the added complexity of the program because of the partitioning. The penalty for partitioning may appear to conflict with the advantages generally attributed to modular programming. However, recall that the partitioning is not simply dividing the computation into manageable parts as done in modular programming. The partitioning of the simulation program to allow sharing among several computers requires concurrent program execution and the use of shared storage.

The method used to estimate the added complexity due to partitioning the program is to assume that the number of intercommunication elements grows linearly with program size and that program complexity (and the associated cost of developing the program) is proportional to the number of intercommunication paths available. Assume the program without partitioning has some number of intercommunication elements N. Then the number of paths between elements is $N(N-1)/2$. If the program size, and thus the number of elements increases by a factor of k because of partitioning, the number of paths becomes $kN(kN-1)/2$. Thus, the number of intercommmunication paths, and therefore the complexity, grows as the square of k. This is the factor used as a measure of the programming effort required when a program is partitioned among several processors.

Table 9 shows the number of partitions used in each configuration and the resulting software cost. The partitions were determined by dividing the computation problem among computers such that the computation rate limits were met and the number of partitions was minimized.

<u>Support Cost.</u> Annual support costs are shown in Table 7. The cost for hardware support is estimated as one per cent of the initial hardware cost per month per system. The annual cost for software support is estimated as ten per cent of the initial software cost. The reason for these estimates was explained above in the discussion of maintenance.

TABLE 9. SOFTWARE COST FOR VARIOUS CONFIGURATIONS

CONFIGURATION	SOFTWARE PARTITIONS			SOFTWARE COST ($1000)
	CPT	OFT	ACMT	
Separate Computer Systems Each Cockpit	1	1	2	2,297
Separate Computer System Each Cockpit (W/Redun)	1	1	2	2,297
Shared Computers with Min. Hardware	1	1	3	2,545
Shared Computers with Min. Hardware (with redundancy)	1	1	3	2,545
Super Mini-Computers	1	1	1	2,070
Super Mini-Computers with redundancy	1	1	1	2,070
Single Large Computer	1	1	1	2,070
Single Large Computer (with redundancy)	1	1	1	2,070
Microcomputers	1	3	6	3,[illegible]

Risk

Risk in the development of the software is an important factor in the choice of an architecture for a simulator complex. The single large computer presents the lowest risk (provided the initial estimate of the computer requirement is not so low that it results in the need for an additional computer). The risk is low because the problem requires no partitioning and the computer has the highest flexibility.

The single minicomputer driving one or more cockpits presents the next lowest risk. This implementation does not have the flexibility of the large single computer, but it requires no partitioning of the problem and does not require several computers to work together. Multiple computers performing the job result in the highest risk. The increased risk in a multicomputer implementation of the problem is the result of the need for partitioning the program among the computers and the concurrent operation of the programs with its associated timing and synchronization problems. Thus the configurations shown in Figures 2, 3 and 5 present successively higher risk factors.

The microcomputer implementation provides the highest risk, so high that such an implementation is not recommended. Neither the partitioning problem nor the control problem has been solved--this alone is enough to eliminate the microcomputer from consideration. In addition, the level of support software available for microprocessors is far below what is available for minicomputers or large computers.

ADDING A REDUNDANT COMPUTER

The computer complex is large enough to warrant consideration of a redundant computer to increase availability. Each of these configurations lends itself to use of redundancy in order to improve system availability. It is assumed in this analysis that the additional computers do not interact and that the device for switching computers in and out of the circuit does not affect the reliability. Although these assumptions cannot be realized in practice, the effect is minor and does not change the result of the analysis.

The determination of whether a redundant computer is cost effective requires the calculation of the increased availability the results from the addition and the derivation of costs for simulator downtime. Assume the simulator system costs shown in Table 10. The total acquisition cost for three simulator complexes is then $90 million. If the life cycle maintenance cost is assumed to be one per cent of the initial acquisition cost per month as it was in the computer system analysis (a very conservative estimate when the whole complex is considered), the life cycle cost for the complexes is $198 million. Since this is an order of magnitude greater than the life cycle cost of the computer configurations being considered, a single cost for an hour of lost time applicable to any of the configurations can be established.

TABLE 10. COST OF DOWNTIME

TYPE	COST (1000'S)	HARDWARE COST PER HOUR	LABOR COST PER HOUR	TOTAL PER HOUR
CPT	800	47	40	87
OFT WO/VISUAL	1500	98	40	138
OFT W/VISUAL	3000	176	40	216
ACMT	6000	[illegible]	40	432

If the simulators are used 52 weeks per year, 6 days per week, 12 hours per day over a 10 year life, one hour of time on the simulators based on first cost is the amount shown in the third column of Table 10. The cost of the lost personnel time should also be included. On the average, each cockpit will have one pilot and one instructor. If manpower costs are assumed to be $20 per hour, this gives the personnel cost shown in the fourth column of Table 10. The fifth column shows the total cost per hour of downtime for each type of simulator.

The lost time caused by computer failure for each system is calculated from the data used in computing the availability. Column two of Table 11 shows the result of applying the lost time to the cost data given in Table 10. This is the cost of lost time for three configurations of computers. Table 11 shows the saving achieved by adding a redundant computer to four of the configurations. No redundancy is considered in the microcomputer implementation, because its one-card configuration allows changing of the whole computer as the normal mode of maintenance.

Column four of Table 11 shows the life cycle cost of adding a redundant computer to each system configuration. The saving achieved by adding redundancy is greatest for the minicomputer systems and not as great for the super minicomputer systems. In the case of the large computer, the cost of redundancy exceeds the cost of the downtime that can be saved.

TABLE 11. SAVING BY USE OF A REDUNDANT COMPUTER

CONFIGURATION	LIFE CYCLE COST OF DWNTM MILLIONS	SAVING BY USING REDUN	COST OF USING REDUN
Separate Computer Systems Each Cockpit	[illegible]	----	----
Separate Computer System Each Cockpit (w Redun)	[illegible]	[illegible]	[illegible]
Shared Computers with Min. Hardware	[illegible]	----	----
Shared Computers with Min. Hardware (with redundancy)	[illegible]	[illegible]	[illegible]
Super Mini-Computers	[illegible]	----	----
Super Mini-Computers (with redundancy)	[illegible]	[illegible]	[illegible]
Single Large Computer	[illegible]	----	----
Single Large Computer (with redundancy)	[illegible]	[illegible]	[illegible]
Microcomputers	[illegible]	----	----

RELATIVE ADVANTAGES AND DISADVANTAGES

The relative ratings of each configuration considered in several important areas are given in Table 12. Availability and cost comparisons are based upon data shown in Tables 5 and 7. The assessment of expansion capability and risk is based upon the discussion given above.

RECOMMENDED SYSTEM

The recommended configuration is the one using super-fast minicomputers. Three computers are required, two to handle the computation load and a spare computer to increase system availability. This system has a cost advantage over a system using conventional minicomputers and provides a reasonable expansion capability. It is not as flexible in adding another cockpit to the system, because any addition beyond the capability of the two active computers proposed requires addition of a relatively expensive computer.

SUMMARY AND CONCLUSIONS

This study provides an evaluation of computer configurations that might be applied to a simulator complex. The computer configurations that have been considered give an insight into the effect of various computer arrangements in terms of cost, maintenance, availability, and risk. More important than the numbers themselves is the procedure used, because this procedure can be used to address other configurations and other numerical values for the variable involved. This procedure is recommended for use in evaluating more detailed implementations provided by contractors.

The treatment of computers was limited to consideration of the general characteristics of each generic class of computer, with no assessment of specific manufacturer's products. The classes considered are (1) large general-purpose computers, (2) super minicomputers, (3) minicomputers and (4) microcomputers. Nine configurations were considered, two using large computers, two using super minicomputers, four using minicomputers, and one using microcomputers. A summary of the tradeoff among the various systems shows the relative advantage of each approach.

TABLE 12. TRADEOFF SUMMARY TABLE

DESCRIPTION		MINI-COMPUTER SYSTEM								
		SEPARATE EACH COCKPIT	SEPARATE EACH COCKPIT W/REDUN	SHARED MIN. HDWR	SHARED MIN. HDWR W/REDUN	SUPER MINI COMPUTER	SUPER MINI COMPUTER W/REDUN	SINGLE LARGE COMPUTER	SINGLE LARGE COMPUTER W REDUN	MICRO-COMPUTER SYSTEM
HARDWARE COST		MEDIUM HIGH	MEDIUM HIGH	MEDIUM	MEDIUM	LOW	LOW	HIGH	VERY HIGH	LOWEST
SOFTWARE COST		MEDIUM	MEDIUM	MEDIUM	MEDIUM	LOW	LOW	LOW	LOW	HIGHEST
EXPANSION	MAJOR	GOOD	GOOD	GOOD	GOOD	MEDIUM	MEDIUM	POOR	POOR	GOOD
	MINOR	FAIR	FAIR	FAIR	FAIR	FAIR	GOOD	POOR	GOOD	GOOD
SYSTEM AVAILABILITY		FAIR	GOOD	FAIR	GOOD	FAIR	GOOD	POOR	GOOD	GOOD
MAINTENANCE/LOGISTIC COST		MEDIUM HIGH	MEDIUM HIGH	MEDIUM	MEDIUM	LOW	LOW	HIGH	VERY HIGH	LOWEST
LIFE CYCLE COST		MEDIUM HIGH	MEDIUM HIGH	MEDIUM	MEDIUM MEDIUM	LOW	LOW	MEDIUM HIGH	VERY HIGH	LOWEST
RISK		LOW	LOW	LOW	LOW	LOW	LOW	LOW	LOW	HIGH

Recommended System

The analysis indicates that the best approach to implementation of the simulators is use of super minicomputers. This type of computer, now becoming available, offers a significant cost advantage over the minicomputers used in the most recent simulators. The large computer and the microcomputer were found not suitable for this application.

This is not a surprising result. It affirms the fact that the multiple-cockpit flight simulator is not significantly different from flight simulators of recent vintage and should be implemented in much the same fashion. The difference in the recommended system for this application is the recent development of super minicomputers which provide several times the capability of the minicomputers of a few years ago. The recommended configuration consists of a super minicomputer performing the computations required for a CPT, four OFT's and an ACMT. Three computers are included in each complex, two computers to share the computation load and a redundant computer that can be used to replace either of the others in case of failure. This configuration provides a significant cost advantage over a system using conventional minicomputers.

The use of a large-scale, general-purpose computer is rejected, because that approach is more expensive than use of multiple minicomputers and results in a lower availability. Although the lower availability could be corrected by the use of a redundant system, the addition of a second computer makes the cost tradeoff even less attractive. It is instructive to look at the reason for this phenomenon in view of the use of large computer complexes for ticket reservation systems and other applications that seem to require much processing and the same high degree of reliability. The difference is that the applications where the large computers show an advantage are those where the problem is the processing of vast amounts of related data. The simulator application is a problem where a dozen entirely separate problems are being solved.

If large computers are not the direction to go, it would seem that smaller computers must be the right answer. In the long range, this may be true. However, for immediate implementation of a computer complex, the risk of entering a new technology far outweighs the advantage to be gained. The problems of control of multiple microcomputers in the simulator environment is being studied, but there is no suitable proven solution. Partitioning the problem for the microprocessor is another unanswered question. Software design aids for microprocessors are not as well developed as those for larger machines, and this would add a great risk to the overall project schedule and cost if microcomputers were selected. These problems should be solved in the R&D arena rather than on a major simulator procurement.

Areas for Further Research

This analysis gives an overview of some of the considerations in choosing a computer configuration for a simulator system. In preparing this study, the authors have been forced to rely upon estimates based upon experience and reasonable extrapolation of known results. Several areas touched upon in this study require further research to define the system better and to provide a firm basis for choice.

Super Minicomputers. The new class of super minicomputers appears to offer the most attractive solution to the computation problem. However, the lack of experience in applying this kind of computer indicates a need for closer monitoring of contractor effort in evaluating this configuration.

Computer Benchmarks. Use of the average instruction execution time in evaluating computer performance is one of the major weaknesses in this study and in the trainer procurement process. Use of modern components such as cache memory, pipeline processing, and floating-point processors and the use of high-level languages provide computer systems whose performance cannot be determined by such a simple measure. Instead of measuring performance by use of an assumed instruction mix, performance should be measured by executing computer programs typical of the application on the machine to be evaluated and measuring execution time and storage required. Developing and validating such a set of programs should be pursued.

Multiprocessor Systems. Use of multiple processors for real-time simulation requires further study to reduce the risks. Work in partitioning the problem, control algorithms, and configuration of processors and memory for this application should be continued. This research will apply to both minicomputer networks in the immediate future and to microcomputer networks now becoming a viable method for simulator implementation.

Interrupt-Driven Systems. Simulators for training ordinarily use a fixed frame computation in which the total task to be performed is divided into subframes to be computed at various rates (e.g., 30, 15, 7.5 times per second). Research should be performed to determine the advantages and disadvantages in using in interrupt-driven system which allows subframes to be processed in the time left over after the mainframe computation. This seems to offer a more effective use of time available than the conventional method.

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Assessment of Simulator Visual Cueing Effectiveness by Psychophysical Techniques

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Joe De Maio and Rebecca Brooks

ABSTRACT

Growing emphasis on simulation of low altitude and air-to-air tactical scenarios has greatly increased the requirement for simulator visual systems capable of providing the pilot high-fidelity out-of-the-cockpit cues. Evaluation of visual system performance through simulator flying studies has been the primary measure of system quality. However, such studies can be costly and time consuming, and often they provide equivocal results. The present study investigated the use of psychophysical measurement methodology to provide a quick, low-cost evaluation of the altitude cues provided by five visual system displays.

Thirty Air Force pilots made estimates of the altitude above ground level (AGL) shown in slides of visual system displays varying in object density and object detail. Slides showed a 90° field-of-view scene taken in the F-16 cockpit of the Advanced Simulator for Pilot Training. Eight altitudes (range 50-400 ft AGL) were presented for each visual scene condition. A random sequence of 40 slides (8 altitudes X 5 scenes) was presented three times. Power functions relating perceived to actual altitude were determined. Reliable differences were found between the displays which accorded well with differences found in a simulator flying study using the same display environments. Results are discussed in terms of display features and the measurement methodology.

INTRODUCTION

As a result of the current trend in flight simulation toward tactical flight and combat scenarios, a need exists for methodologies to evaluate the effectiveness of visual system displays in providing out-of-the-cockpit flight cues. The simulator visual system presents the pilot with a variety of cues he needs to perform his task. These range from airspeed, altitude, and navigation cues to cues relating to the presence, range, and behavior of threats and targets. Simulator flying studies have been performed to determine the effectiveness of texture (Edwards et al, 1981), color (Kellogg et al, 1981), and three-dimensional objects (Rinalducci et al, 1981) in providing low-altitude flight cues. While such studies provide the ultimate measure of the effectiveness of a visual system display in providing cues needed to perform simulated flight tasks, they can have severe methodological limitations. The requirements of such studies for simulator time, subject time, and development time are great. Simply to study the effectiveness of one type of visual cue can require as much as 50 hours of simulator time, even if only a small number of subjects is run. Therefore, only a limited number of visual environment displays may be investigated. In order to perform the parametric studies required for the design of effective simulator visual environments, techniques are required for assessing the cueing effectiveness of visual displays quickly and at low cost. Such techniques might be used to screen candidate displays so that only the most effective need be examined in more comprehensive simulator flight studies.The purpose of the present research was two-fold. The primary purpose was to determine th effectiveness of a methodology for assessing the quality of simulator visual displays quickly and at low cost. The technique investigated involved having pilots estimate the altitude above ground level (AGL) in static (slide) presentations of a simulator visual system display. This technique permits "mass production" evaluation of visual displays but does not permit examination or evaluation of the capability of visual scenes to provide altitude cues based on scene dynamics. Because of this limitation in the quality of altitude cues available, it was necessary to compare the results of the static estimation technique with those of a dynamic, simulator flying approach.

A second purpose of the research was to examine the aspects of scene content, object density, and object detail in order to determine their effects on the perception of altitude. Two aspects of visual scene content were investigated. These were the density of 3-dimensional objects in the environment and the level of detail of the objects.

METHOD

Materials

Stimulus materials were 35 mm color slides taken with a 90° field-of-view lens in the F-16 cockpit of the Advanced Simulator for Pilot Training (ASPT) at Williams AFB. The out-of-the-cockpit scene consisted of flat terrain with 200 ft aiming towers at eight-mile separation. Altitude cues of varying quality were provided by inverted pyramids. Condition 1 and condition 2 were high detail conditions in which the sides of the pyramids were black and the base (top) was white. Condition 3 and condition 4 were medium detail conditions in which the pyramids were all black. Two conditions (conditions 1 and 3) were high object density conditions, with the mean distance between pyramids equal to 1500 ft. In the low density conditions (condititons 2 and 4), separation between pyramids was 4500 ft. In all four conditions the pyramids were 50 ft tall. A fifth condition was intended to have lowest detail. In this condition, the pyramids were displayed so that only the base was visible above the ground. Thus, the pyramid had the appearance of a triangle laying flat on the ground.

Unfortunately, the level of detail was so low that the triangles appeared only as scintillations in the dynamic scene as the objects moved across the raster lines of the CRT display and were nearly invisible in the static display. As a result, only the 200 ft aiming towers, separated by eight miles, provide any real altitude cue. In all conditions, eight altitudes, ranging from 50 to 400 ft in 50 ft increments, were presented. A single set of 40 slides was used in which each of the 40 altitude-visual environment conditions was presented once in random sequence.

Subjects

Thirty pilots in A-10 combat crew training served as subjects. Their flying experience ranged from approximately 400 hr to 3000 hr. None had had any previous experience in ASPT.

Procedure

Subjects were run in groups of ten in a squadron meeting room having projection facilities. Subjects were seated from 15 to 25 feet from the screen image, which was 7-1/2 ft wide. At the start of the session, the experimenter explained the purpose of the research. The experimenter then explained that a sequence of 40 color slides showing straight and level flight would be presented. Subjects were told that the slides would show five different simulator visual environments. Since none of the subjects had ASPT experience, they were told that the range of altitudes would be 50 to 400 ft. Subjects were not informed of the size of the inverted pyramids since no attempt was made to equate the size of the static display with that of the display in the simulator cockpit. Subjects were then given response sheets and told that when the first slide appeared, they were to estimate the altitude (AGL) shown. Estimates for subsequent slides were to be made relative to the first. Thus, if the estimated altitude for the first slide was 100 ft AGL and the second slide appeared at twice as high an altitude, the estimate would be 200 ft AGL. Subjects viewed the sequence of 40 slides three times without feedback. Each slide was presented for eight seconds with the interval between slides being only the cycle time of the carrousel projector.

RESULTS

The first slide presentation sequence was treated as practice and the altitude estimates from the second and third runs only were analyzed. The data were analyzed by first transforming the actual and estimated altitudes to logarithms. Estimated altitudes were then adjusted for each subject's overall bias. A least-squares linear function was determined relating log estimated altitude to log actual altitude for each of the five visual scenes. The slope of the log-log linear function is the power of the function relating estimated altitude to actual altitude. A power (slope) of 1.0 indicates perfectly accurate estimate of altitude. A power of greater than 1.0 indicates expansion or overestimation of changes in altitude, and a power of less than 1.0 indicates compression or underestimation of changes in altitude (Kling and Riggs, 1971).

In addition to giving the relationship between actual and estimated changes in altitude, the technique gives a zero intercept. This zero intercept can be considered an estimate of what it would look like "sitting on the deck" under the display conditions used in the study, although it may not be an accurate estimate of the perceived zero in the simulator. However, in a relative sense, the zero measures one aspect of the quality of altitude cues provided by the different visual scenes.

Altitude estimates from all five visual scenes showed marked compression (see Table 1). In addition, intercepts for all scenes were inflated. The inflation of the intercept tended to be most pronounced when compression was most marked. The lowest detail scene (condition 5) showed the greatest compression with a log-log slope (B) of .197. The intercept (A) was also greatest for this condition ($\bar{a}$ = 1.85). Thus, for this condition, the estimated altitude was 85 ft at 50 ft actual and 122 ft at 400 ft actual. Clearly the altitude cues provided by this scene are very poor.

TABLE 1

Condition	Object Density	Object Detail	B	A
1	High	High	.82	.31
2	Low	High	.51	1.1
3	High	Med	.70	.51
4	Low	Med	.50	1.1
5	Low	Low	.20	1.85

Slopes (B) and Intercepts (A) of the Altitude Estimation Functions for the Five Visual Display Environment Conditions

The best altitude cues were provided by the high detail, high density scene (condition 1). The power, B, was .821 and A was .314. Thus, estimated altitude was 25 ft at 50 ft actual and 257 ft at 400 ft actual. Assessment of the differential altitude cueing effectiveness of the five environments was accomplished by an analysis of variance on the slopes of the altitude estimation functions (see Table 2). The effect of object density on altitude estimation was determined by post-hoc comparision of

TABLE 2

SOURCE	MEAN SQUARE	D. F.	F-RATIO	P
TOTAL	.113	149	-	-
DISPLAY CONDITIONS	1.684	4	39.6	.001
ERROR	.043	116	-	-

Results of Repeated Measures ANOVA on Slopes of the Altitude Estimation Functions for Five Visual Display Conditions

conditions 1 and 3 with conditions 2 and 4. A Scheffe' test showed the high object density conditions to provide significantly better altitude cueing than the low object density environments ($F(4,116) = 45.5$, $p < .01$). The effect of object detail was determined by comparison of conditions 1 and 2 with conditions 3 and 4. This difference was significant ($F(4,116) = 10.8$, $p < .01$) with the high detail environments providing superior altitude cueing. There was a suggestion of an interaction between object density and object detail. The effect of object detail on the slope of the altitude estimation function was greater in the high object density condition than in the low object density condition. Unfortunately the detail-density interaction failed to reach significance ($F(4,116) < 2.4$, $.10 > p > .05$).

Condition 5 was ommited from the post-hoc analysis because it was unclear how this condition should be classified. Many of the subjects reported that they had difficulty in distinguishing the triangles from flaws in the picture. Therefore condition 5 could be considered either a low density, low detail condition or an empty field condition, with only a horizo line and the distant aiming towers. In any event the altitude cueing effectiveness of condition 5 was very poor indeed and was substantially poorer than that of any of the environments containing 3-dimensional objects.

DISCUSSION

The differences obtained in subjects' ability to estimate altitude in the different visual environments have pointed up the sensitivity of the magnitude estimation technique. Substantial differences in altitude cueing effectiveness were found as a function of both object density and object detail. There was also a suggestion of an interaction between object density and object detail, although this interaction was non-significant.

Unfortunately the present data give no indication of the validity of the approach for making judgements about the effect of visual scene content on simulator flying performance.To determine the validity of the technique, it is neccessary to compare the results of the magnitude estimation technique with those of a simulator flying study. Rinalducci et al (1981) performed a simulator flying study on the Advanced Simulator for Pilot Training using three of the environments used in the present study (conditions 1,3 and 5). He monitored performance at maintaining a constant altitude of 200 ft AGL while flying through each environment. Although the variability in performance was high, significant differences were obtained between condition 1 performance and condition 5 performance, with both average altitude and RMS altitude performance being superior in condition 1. Performance in condition 3 was slightly worse than that in condition 1 but was not significantly different from either condition 1 or condition 5. The qualitative similarity between the present data and those of Rinalducci et al suggests that the magnitude estimation technique is sensitive to the effect of altitude cues needed for simulator flight. In fact the present technique may be more sensitive to the effects of visual display factors on perception than is simulator flying performance.

CONCLUSIONS

1. The magnitude estimation approach has been shown to be a usable technique for assessing the altitude cueing effectiveness of visual displays. The technique is very sensitive to differences in the cueing effectiveness of diferent visual environments. Results obtained with the magnitude estimation technique are comparable to those obtained in simulated flight studies, but the magnitude estimation technique provides equal or greater sensitivity at lower cost.

2. The density of objects in the visual environment was found to be a potent, determining factor in the cueing effectiveness of visual displays.

3. Object detail was found to be an important altitude cue. There was a suggestion of an interaction between object density and object detail in perception of altitude.

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METHODOLOGY TO ASSESS IN-FLIGHT PERFORMANCE FOR AIR-TO-AIR COMBAT TRAINING

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ABSTRACT

The Navy's Tactical Aircrew Combat Training System (TACTS) provides the instrumentation necessary to record in-flight performance of aircrews during air-to-air combat training. Data recorded on TACTS has been an important source of information for the development of objective flight performance criteria. This paper discusses research related to the development and application of in-flight measures of air combat performance. Procedures for systematic development of aircrew performance measures are identified and discussed. A generic methodology is proposed which will eventually lead to a prescriptive model for performance measurement system development. Some of the many applications of objective flight performance criteria include training progress evaluation, training methodology and effectiveness studies, and learning acquisition and transfer studies.

INTRODUCTION

Instrumentation

The Navy's Tactical Aircrew Combat Training System (TACTS) enables aircrews to monitor in real time various air combat exercises, and through its replay capability, provides the opportunity to debrief and evaluate pilot tactics, maneuvers, and weapon delivery accuracy. The U.S. Air Force second-generation version of this system is referred to as Air Combat Maneuvering Instrumentation (ACMI). Four major subsystems comprise the TACTS/ACMI System:

- **Airborne Instrumentation Subsystem (AIS)** - Uses a pod attached to the aircraft which measures flight dynamics information, senses weapon firing signals, and transmits data to the ground through the TIS.

- **Tracking Instrumentation Subsystem (TIS)** - Uses a series of unmanned remote tracking stations communicating with a master tracking station in order to monitor aircraft in a specified airspace.

- **Control and Computation Subsystem (CCS)** - Converts data received from the TIS into suitable form for display. Uses a pod attached to the aircraft which measures flight dynamics information and senses weapon firing.

- **Display and Debriefing Subsystem (DDS)** - Serves as a control center and display station.

Figures 1 and 2 illustrate the major TACTS/ACMI subsystems and their interrelationships. Some of the more important training features of TACTS/ACMI follow:

- Real-time tracking including position, velocity, acceleration, altitude, and angular rate measurement of aircraft engaged in air combat training.

- Tape playback of flight history data, complete with pictorial display of the air-to-air engagement and voice transmissions.

- Both digital and graphic hardcopy printouts of flight data, aircraft state vector positions, cockpit view of engaged aircraft, and mission summary data.

- Computer-generated estimates of the results of weapon firing.

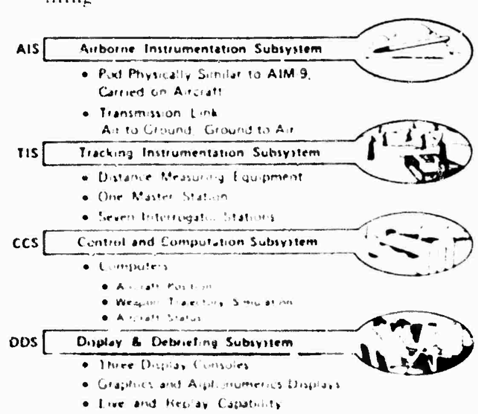

Figure 1 Tactical Aircrew Combat Training System (TACTS)

Figure 2 General Configuration of TACTS Subsystems

Recent engineering advances on TACTS have incorporated instrumentation required for training aircrews in ground attack missions as well. Some of the added capabilities include No-Drop Bomb Scoring, electronic warfare, and mine laying. This research paper, however, will concentrate on the traditional role of TACTS/ACMI in assessing performance of aircrews during air combat training.

Need for a Performance Measurement System

The Navy developed TACTS in response to lessons learned in Viet Nam indicating that U.S. pilot performance in air combat was below acceptable standards. A plausible reason for poor performance was thought to be inadequate pilot training in the use of proper weapon fire boundaries. It was then suggested that aircrew training could be substantially improved by providing an instrumented range able to monitor and record air combat engagements and to simulate weapon firing results. TACTS was designed to meet these urgent demands for training instrumentation, so engineering emphasis was necessarily placed on real-time tracking of air-to-air engagements, weapon envelope simulation, and enhanced aircrew debrief via the DDS.

Present range instrumentation capabilities of TACTS provide a unique opportunity for aircrews to practice both flying and shooting tasks under realistic flight conditions and within an information-rich training environment. It is important to realize, however, that since TACTS is designed primarily to enhance debriefing of individual air combat engagements, the resulting system design does not include a capability to collect and analyze cumulative performance results or to depict statistical trends. Analysis of trend data and application of other performance assessment methods are needed for:

- Training progress evaluation by
  - operational aircrews
  - training officers
- Combat readiness estimation by
  - fleet commanders
  - DoD analysis groups
- Tactics development by
  - fleet squadrons
  - operational test and evaluation squadrons
- Research Development Test and Evaluation (RDT&E) by
  - weapon system developers
  - Government research centers

Performance assessment is appropriately referred to by instructional system designers as the best means to determine that learning has occurred following training. Without performance measurement there can be no assurance that any training system, including TACTS, is meeting its design objectives. Application of performance assessment procedures will enable aircrews undergoing training on TACTS to:

- Evaluate progress toward completing specific instructional objectives
- Estimate combat readiness of individual aircrew members and operational units
- Diagnose training deficiencies and provide corrective feedback, and in general, to remove redundancy and inefficiency in training through application of performance-based feedback

Research Background

Since early research related to the development of air combat performance measures was discussed in several technical reports and previously published articles, it will not be treated in great detail here.

The first technical report was written in 1977 for the Naval Aerospace Research Laboratory, and this report described an analytic framework for conducting performance criterion research. This analytic framework described the TACTS as a system which includes *aircrews, instructors, aircraft, weapons, missions* and *operating environment*. The technical approach used calls for obtaining performance measures within a system framework which identifies the above TACTS elements, defines the training mission and the operational environment, and provides measurement methods sensitive to the influence of variables identified in the total TACTS system. Each set of performance data collected on TACTS is described and referenced using this system framework (i.e., training mission, system elements and operating environment). Thus performance variations can be related back to specific elements and operating conditions. If desirable, the combination of elements (aircraft, weapons, aircrews, etc.) and the training mission can be systematically controlled to assess their influence on system performance.[4]

A second research report presented measurement criteria and assessment methods for evaluating Navy aircrew missile envelope recognition performance. Two generic measurement methods were used to assess aircrew performance in missile firing accuracy.

First, a criterion-referenced assessment method was applied to score missile launch success (percent hits) and to compute task accuracy measures (error from prescribed missile launch boundary). A pilot must fire his weapon within this prescribed boundary to obtain a hit, and the distance from a proper launch window can be used to compute task accuracy (error scored) measures.

Second, norm-referenced measures, based on empirical data (mean ± one standard deviation), were used to evaluate performance related to group standards. A combination of norm-referenced and criterion-referenced measures has been proposed for other specific air combat tasks, i.e., radar search and acquisition, visual search and acquisition, tactics and maneuvers, etc.

Another report presented a synthesis and application of the above measurement methods. In addition, preliminary measurement validation tests were presented. Results of these preliminary validation tests showed statistical support for selection of task-based measures used to assess aircrew performance in air-to-air combat.

Finally, more extensive statistical validation tests were conducted using multiple linear regression analysis in a double cross-validation design. Measures related to successful completion of various air combat tasks have reliably predicted 45 percent of the variance in final engagement outcome scores. These tasks include early visual identification of an opponent, missile fire accuracy, shooter-to-target pointing accuracy, and maneuvering to obtain a first-shot advantage.

PERFORMANCE MEASUREMENT SYSTEM DEVELOPMENT

Research Strategy

Meister (1978) has summarized characteristics which distinguish measurement approaches based upon controlled experimentation and those measurement approaches related to complex systems. An important distinction made by Meister is that measures obtained in complex systems are taken in reference to the entire task, or job, which is performed in the context of the actual (uncontrolled) work environment.

In contrast, laboratory experimental research is conducted under highly controlled conditions. Isolated or synthetic tasks are performed while selected variables are systematically manipulated. Measures obtained in the laboratory are usually directly related to experimental hypotheses which guide the measurement selection process, data collection, and analysis procedures used to evaluate experimental results. In complex systems, measures are typically obtained while the system is in operation. It is difficult to measure the performance of individuals under these circumstances because each individual's effort is embedded within a system framework. Meister proposes to measure performance at the individual, team and systems levels. This will help us to understand the relative contribution of each level in meeting overall system performance requirements.

Another major difficulty encountered with aircrew performance measurement in complex systems is the determination of exactly what measures to take out of the total available. While there are many studies of aircrew performance in the literature, no widely accepted research strategy has evolved which specifically outlines the steps or procedures required to select and validate aircrew performance measures and assessment methods.

Vreuls and Wooldridge (1977) have discussed in broad outline many important aspects of performance measurement research. These authors propose a systems-oriented, statistically based approach to develop aircrew performance measurement methods. Some of the more important ideas discussed by Vreuls and Wooldridge in their article are briefly summarized below.

- **Systems Orientation** – Aircrew performance is embedded in a complex system and is influenced by such factors as tactical doctrine, mission plan, weather, weapon availability, aircraft subsystem capabilities, and operating status.

- **Task Analysis** – The measurement specialist must devise a means to sample aircrew tasks that are most important to measure (i.e., tasks and measures that are best for describing, predicting, and understanding aircrew and system performance).

- **Statistical Approach** – A multi-variate statistical approach is proposed as the "only method powerful enough to deal with the complexity of the real world" (i.e., in which many variables interact to influence performance measures obtained).

- **Measurement Selection** – Measures should be selected which satisfy statistical requirements for validity and reliability and which are accepted by the operational user.

The above researchers have identified some key principles to consider during the development of aircrew performance criteria. Application of such principles forms the basis of a systems approach to performance measurement specification which emphasizes generic methods and test procedures.

System Development Model

Figure 3 presents a proposed model for Performance Measurement System (PMS) development. The model specifies a four-phase research and development program which begins by defining the training mission and operational task structure and ends with implementation of a PMS. The four phases of PMS development (analysis, description, validation and implementation) are briefly described below.

- **Analysis** – During the analysis phase of research, information related to the mission and its associated operational tasks is collected. Operational task data are brought to a level of analysis required to specify performance-based training objectives and to select a preliminary measurement set. (11)

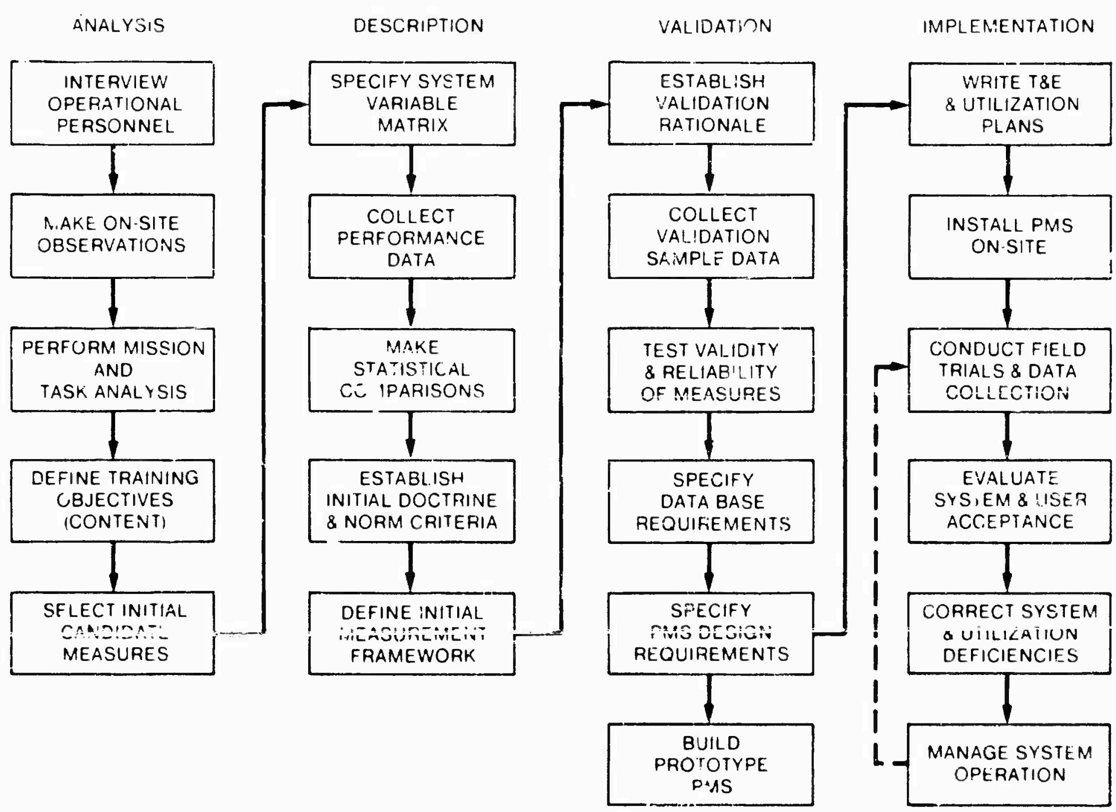

Figure 3 Performance Measurement System (PMS) Development Flow Chart

- **Description** – A variable matrix which identifies training or operational system elements, in this case aircrews aircraft, weapons and mission factors. The variable matrix serves as an initial systems framework for guiding performance data collection and analysis. Data collected on the training system can be categorized for later analysis with respect to the key operating elements as potential sources of variance of the training system. In other words, statistical sample comparisons are made between various aircraft types, weapon types, mission characteristics, aircrew changes, etc. These initial descriptive statistical comparisons provide the measurement specialist with initial information regarding the sensitivity of measures to discriminate expected performance differences at the system level. Table 1 presents an example of a variable matrix which was used in air combat performance measurement development. (See Ref (11).)

- **Validation** – Information from task analysis and descriptive statistical comparisons (i.e., from analysis and descriptive phases) is used as a foundation to establish a preliminary measurement framework. The measurement framework represents a hypothetical position regarding operational tasks their associated performance measures, and the potential influence of system-level variables on overall performance in the operational training system. Since the initial measurement framework is based on the researcher's *a priori* judgments about key variables and their relationships to the operating system, the resulting framework represents a theoretical structure requiring empirical validation. (See Ref (4).)

The validation phase of performance measurement research is concerned with establishing an objective rationale to verify and support initial selection of candidate performance measures. The validation rationale usually is based on the following considerations:

(a) The degree to which candidate measures correlate with overall (terminal) system performance
(b) The ability of the measures to discriminate variations in operator (aircrew) skill level
(c) The reliability of performance measures obtained over repeated applications
(d) User acceptability and ease of implementation

Once a rationale for validation has been established and successfully demonstrated, then data base requirements and functional design features can be specified for hardware and software engineering development of a prototype PMS.

- **Implementation** – An important part of PMS implementation should be preparation of a Test and Evaluation (T&E) plan. The T&E plan should:

(a) Include guidelines for applying the PMS as an integral part of an overall training system
(b) Specify Training Effectiveness Evaluation (TEE) procedures for PMS application.

Procedures outlined above need to be amplified in certain areas and refined in others to formulate a more complete prescriptive model for performance measurement system development. Even at this early stage of their development, such procedural guidelines were a useful aid in the specification of a measurement framework for air combat performance assessment

Table 1. TACTS Training System Components and Variable Matrix

Personnel		Equipment		Mission	
Instructors*	Aircrews	Aircraft	Weapons	Mission	Environment
Experience and training	Adversary and fighter aircrews	Adversary and fighter type	Type	Type (e.g., single or multiple aircraft)	Weather
In-flight and debrief procedures and techniques	Perceptual/motor skills	Performance characteristics and limitations	Design characteristics and limitations	Specific training objectives	Visibility
Content and quality of directive commentary (related to RTOs)	Training and education	Specific design features	Delivery parameters	Tactics and maneuvers specified and/or used	Terrain
Training function and tasks	Flight experience (total, type, crew, section)	Particular weapon and sensor complement	Procedures	Range operating constraints	Traffic
Training aids	ACM experience	System/subsystem operating status	Specific weapon load and selection options	Participating aircraft (mission mix)	Sun
					Miscellaneous

*Including Range Training Officer (RTO) and Flight Leader

Figure 4 shows a simplified Air Combat Maneuvering (ACM) sequence. ACM *mission phases* are written at the top of the figure, while points of measurement related to key aircrew training objectives are indicated in boxes. The solid boxes represent points for which measures are now available, and dotted boxes represent recommended additions to this overall measurement scheme. For example, ACM engagement state models and algorithms for measuring energy maneuverability performance are two essential additions in the final formation of an overall ACM measurement system.

Measures for engagement state are based on obtaining a position advantage, i.e., by measuring an aircraft's proximity to the lethal zone of an adversary aircraft. Measures for energy maneuverability are related to optimizing airspeed for efficient air combat maneuvering, i.e., flying an aircraft to its aerodynamic ideal. Addition of energy-related and maneuvering information to the building blocks model presented in Figure 4 would complete a technical approach that is based on a multi-task, multi-measure method. Table 2 shows short-form definitions of ACM training objectives and also indicates the corresponding candidate performance measures for these objectives. More detailed definitions for training objectives and candidate measures are reported elsewhere. (See Ref. (11).)

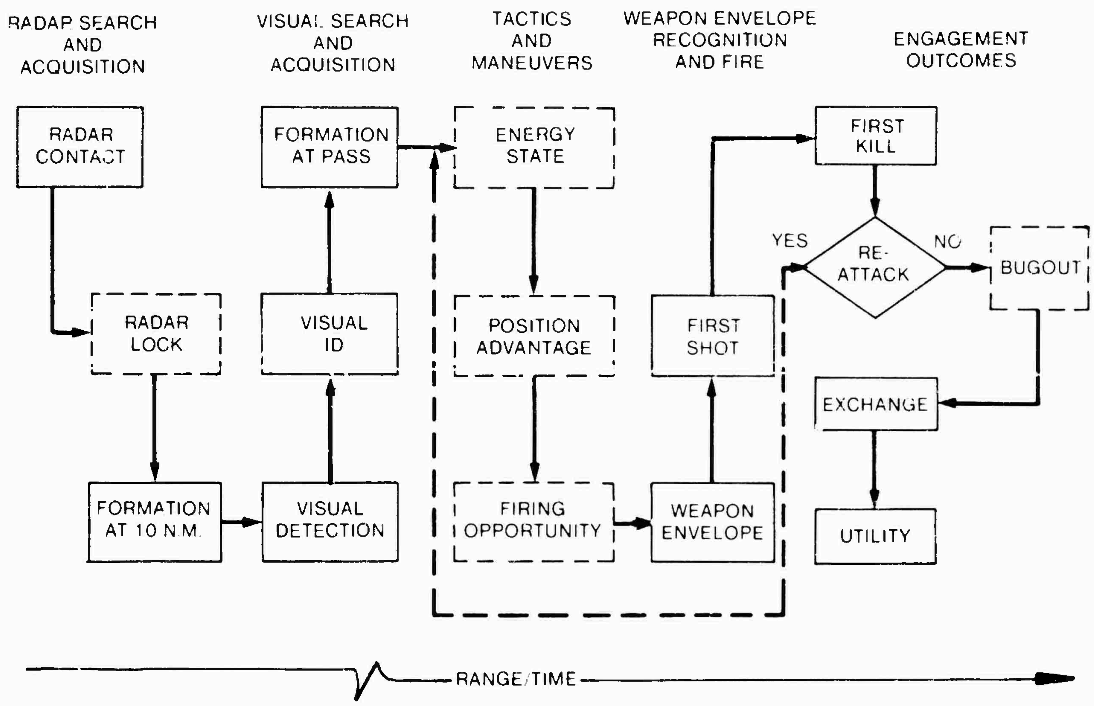

Figure 4 Simplified Air Combat Sequence: Shows Engagement Phases and Measurement Points

Table 2. Air Combat Engagement Analysis

Training Objective	Performance Measure
1. Obtain early radar contact and lock-on	Interaircraft range and success rate (%) over engagements flown
2. Determine adversary attack formation at 10 n.m.	Quantity and position of enemy aircraft
3. Obtain early visual detection of adversary aircraft	Interaircraft range and success rate (%) over engagements flown
4. Obtain early visual identification of adversary aircraft	Interaircraft range and success rate (%) over engagements flown
5. Determine attack formation at initial pass	Quantity and position of enemy aircraft
6. Maintain high energy state	Indicated air speed and altitude (energy package)
7. Gain/maintain position advantage	% or proportion of engagement in offensive, defensive states.
8. Gain firing opportunity	Time and/or % in envelope or fatal offensive state
9. Obtain first shot of engagement	Elapsed time and % first shots
10. Fire weapon in weapon envelope	Interaircraft range, angle-off-tail, pointing angle, airspeed and acceleration parameters
11. Obtain first kill of engagement.	Elapsed time and % first kills
12. Execute successful re-attack.	Iterate 6-11 above
13. Execute successful bugout by staying neutral, maintaining energy, and completing disengagement with no friendly loss.	% neutral, indicated airspeed and altitude, % loss at bugout
14. Obtain favorable exchange (Exch) rate	Ratio of fighter to adversary kills
15. Satisfy mission (utility) requirements	Neutralize threat aircraft and survive or minimize losses

Results of the measurement research program have been directly applied to operational training. A computer-based, air combat debrief system was designed and developed as a prototype to test the feasibility of adding a PMS to TACTS (14,15). The resulting debrief system, currently undergoing further development by NAVTRAEQUIPCEN, is referred to as the Performance Assessment and Appraisal System (PAAS). PAAS design is based on the previously described measurement framework which has been partially validated. (See Ref. (8).)

The debrief system can display numerous graphs depicting statistically summarized performance results from TACTS training sessions. (See Ref. (15).) Data are provided to aircrews in an understandable format for review and diagnostic evaluation of air combat training progress. Figures 5 and 6 present examples of computer-generated graphics used by aircrews to assess their performance in key air combat tasks using PAAS.

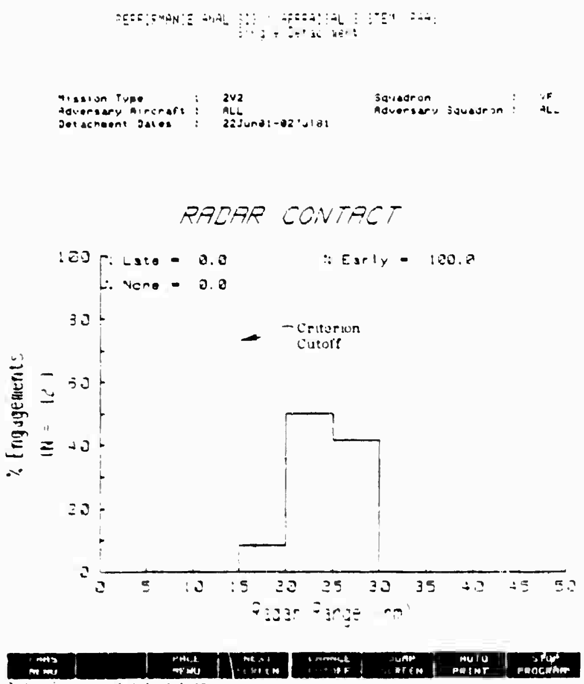

Figure 5 PAAS Graphic Format Used to Evaluate Radar Contact Performance for a Single Training Detachment

It is important to note that the present PAAS provides performance-based feedback *only on non-maneuvering* portions of an air-to-air engagement. Inclusion of measures related to air combat maneuvering is considered necessary to complete the proposed measurement framework (presented in Figure 4). Obtaining air combat *maneuvering* measures, however, will require use of an automated data retrieval system that is tied directly to TACTS/ACMI in order to capture the time history data necessary for analyzing maneuvers. No automated retrieval system is available on TACTS/ACMI today, and would have to be developed.

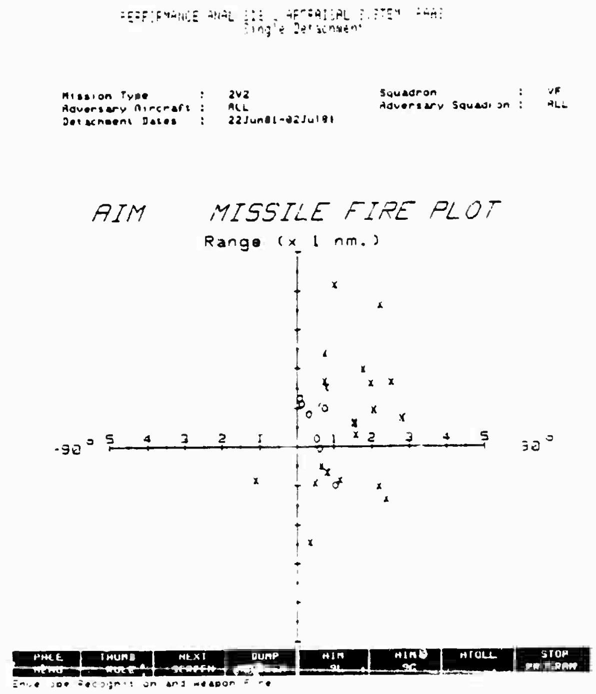

Figure 6 PAAS Graphic Format Used to Evaluate AIM Missile Fire Accuracy (envelope recognition) for a Single Training Detachment

DISCUSSION AND CONCLUSIONS

Performance measurement is an important ingredient to effective training. It is only by measuring performance that we can know if learning has occurred, and whether or not our instruction has succeeded.

Until recently, aircrew training instructors had to rely upon their subjective estimates of student training progress and instructional effectiveness. With the development of instrumented ranges like TACTS, we can now record in-flight performance. Such a capability provides the training community with an opportunity to apply objective performance criteria during the instructional process.

Caution should be raised, however, concerning the advent of instrumented ranges like TACTS, and advanced flight simulators which incorporate recording capabilities. The mere capability to record outputs from these training systems does not necessarily guarantee that such recorded data are valid and reliable measures or that they are appropriately applied. As should be apparent from the contents of this paper and previous publications, much analysis and testing preceded the selection and application of performance measures. Such analysis and testing is an essential precaution against merely adding a PMS as a possible extraneous feature to a training device. Addition of a PMS can enhance training, but it also can conceivably result in *decreased* training value if a PMS is poorly designed and/or inappropriately applied.

This paper discussed application of a task-based measurement approach which capitalized on the availability of TACTS data for *developing*, *validating*, and *applying* air combat performance measures. The proposed PMS development model represents a hopeful first step toward a more refined prescriptive model (or generic methodology) for incorporating systematically developed and validated performance criteria as an integral part of training system design.

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EFFECTIVENESS EVALUATION FOR AIR COMBAT TRAINING

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ABSTRACT

This paper addresses methods developed for evaluating factors involved in Air Combat Maneuvering (ACM) training. In the course of selecting and applying evaluation techniques, a unique situation for a transfer-of-training study was presented: a newly installed ACM simulator co-located with an ACM range. A common, objective performance measurement system was developed for the Air Combat Maneuvering Simulator (ACMS), designated Device 2E6, and the Tactical Aircrew Combat Training System (TACTS) range. The TACTS range was planned as the setting for studying transfer from the simulator to an operational situation.

INTRODUCTION

An early attempt to evaluate pilot trainees in air-to-air combat was known as "pin ball" (USAF, 1945). The "pin ball system" registered hits of frangible bullets on a manned, armor-plated, target aircraft. The system also provided a visual signal to the attacking pilot by turning on a strobe light in the nose of the target aircraft. The fidelity, realism and immediacy of objective feedback were high. As a gunnery trainer "pin ball" was a relatively effective training device, even though it probably did little for the pulse rate of the target aircrewman.

In 1967, NTEC began development of a gunnery practice system based on the use of inexpensive, eye-safe laser transmitters and receivers to simulate firing live rounds. Laser simulation has the advantage of providing an unlimited source of hazard-free "ammunition" at a negligible cost per round. Previous applications of this technology include the Laser Marksmanship Rifle Trainer and the Helicopter Door Gunnery Trainer.

The advent of air-to-air missiles in air combat maneuvering made the application of PIN BALL training techniques very inefficient, and required a technological sophistication beyond laser designators.

Training Air Combat Maneuvering (ACM) skills requires the exercise of a complex pattern of perceptual, psychomotor, physiological cues and procedural elements within a demanding tactical environment. You cannot train such a pattern in a simulator exclusively. Neither can you efficiently learn such a pattern in an aircraft exclusively. Training devices must be designed to complement actual training in aircraft. The increased complexity of fighter aircraft include multiple weapons for ACM employment, multiple systems for acquisition, two-man crews, additional functions required to operate weapons systems, and increases in aircraft performance which require quicker aircrew reaction time. All of these factors mandate increases in both flight time and simulator usage, and effective integration of training devices and aircraft into the fleet ACM training program structure. Improved training can have a force-multiplier effect in ACM, but we must bite the bullet. More training sorties in the air, undoubtedly, are required; and more simulator hours also will contribute to the training process. Maximum contribution of a simulator is contingent upon the integration of proper maintenance and instructor/operator support.

A Training Effectiveness Evaluation (TEE) was initiated by the Human Factors laboratory at the Naval Training Equipment Center (NAVTRAEQUIPCEN) to aid in defining, through objective measurement, how much and what type of integration is required. The TEE effort has been designed to provide data to help determine how well a training system produces a desired result. Such data must be forthcoming if we are to design for (1) optimal simulator/aircraft mix, (2) instructional strategies such as optimal sequencing, or (3) other significant factors that affect the amount and type of training required. The successful quantification of training effectiveness also will provide a data base which can be used for the specification and development of new or modified simulator systems.

The TEE took advantage of a unique situation for the development of such a data base. A recently installed ACM simulator co-located with an ACM range at NAS Oceana, Virginia, was reviewed for the feasibility of conducting a transfer-of-training study. A review of current ACM aircrew training programs, as well as a review of simulator and training device applications, suggested the need for a common Performance Measurement System (PMS) between the Air Combat Maneuvering Simulator (ACMS), designated Device 2E6, and the Tactical Aircrew Combat Training System (TACTS) range.

Device 2E6 is a high technology simulator consisting of two 40-foot diameter domes with an adversary aircraft image projected on the surface of the dome. The adversary image moves in response to inputs from an aircrewman in the opposing dome or in response to computer-controlled or console operator-controlled inputs. Simulated missile firing, as well as gun firing, are possible in the simulator and are accompanied by visual cues. This type of interaction can occur on a 1 versus 1 basis (1v1), on a 2 aircraft versus 1 aircraft basis (2v1), or on a 3 aircraft against one another basis (1v1v1).

The TACTS range permits objective measurements of aircraft spatial relationships, missile maneuvering envelopes and simulated missile firing in an environment that is as close to combat as is possible. The TACTS range instrumentation records selected movements and actions in specially instrumented aircraft as they interact in a "dogfight" over the Atlantic Ocean. The system tracks aircraft operating within an assigned airspace and computes and stores aircraft position, attitude, and weapons-related parameters in real time, permitting a three-dimensional depiction of the engagement to be monitored at a ground station. Radio communications are provided between the ground station supervising the exercise and the participating aircraft. Potentially hazardous flight conditions are automatically detected and brought to the attention of a training supervisor for appropriate action.

It was clear that if a common performance measurement system could be developed, the potential for a classical transfer-of-training (TOT) design and associated statistical analyses for the TEE would be enhanced. Thus, for the first time it appeared feasible to measure transfer of performance from simulator to ACM flight conditions as represented on the TACTS. The ACMS is a one-of-a-kind device and joint operation with TACTS yields quantitative air combat maneuvering performance data which are a direct function of pilot training and performance.

The first step in the TEE was to examine the TACTS range. TACTS was developed to provide aircrews with an objective means for improving missile envelope recognition. The TACTS provides training in a realistic but controlled environment. The trainee receives limited real-time airborne feedback and, later, more thorough "debrief" feedback concerning the effectiveness of weapons firing which are simulated by the TACTS computers at the ground station.

The TEE program also was timely in that it was able to directly support Commander Fighter Wing One (COMFITWING ONE) personnel who were in the process of developing a PMS for the TACTS range. The measurement system being developed for TACTS was entitled The Readiness Index Factor (RIF). It was based upon the Readiness Estimation System (RES) first developed by the Center for Naval Analyses. The RIF provided a measure of the spatial relationship of two or more interacting aircraft and considered the type of weapons employed.

DATA COLLECTION AND ANALYSIS

TACTS data were collected and analyzed using the RIF during two Fleet Fighter ACM Readiness Programs (FFARPs), which comprise a syllabus of "refresher" exercises (1v1, 2v1, 2v2, etc.) for fleet squadrons that span roughly three weeks. One FFARP involved airborne combat exercises employing friendly F-4 aircraft engaged with F-5 and A-4 adversary types. The other FFARP involved F-14 against F-5 and A-4 adversaries. The data indicated that the RIF was sensitive not only to differences in individual aircrews, but also to aircraft variables as well.

Figure 1 contains one comparison of such differences.

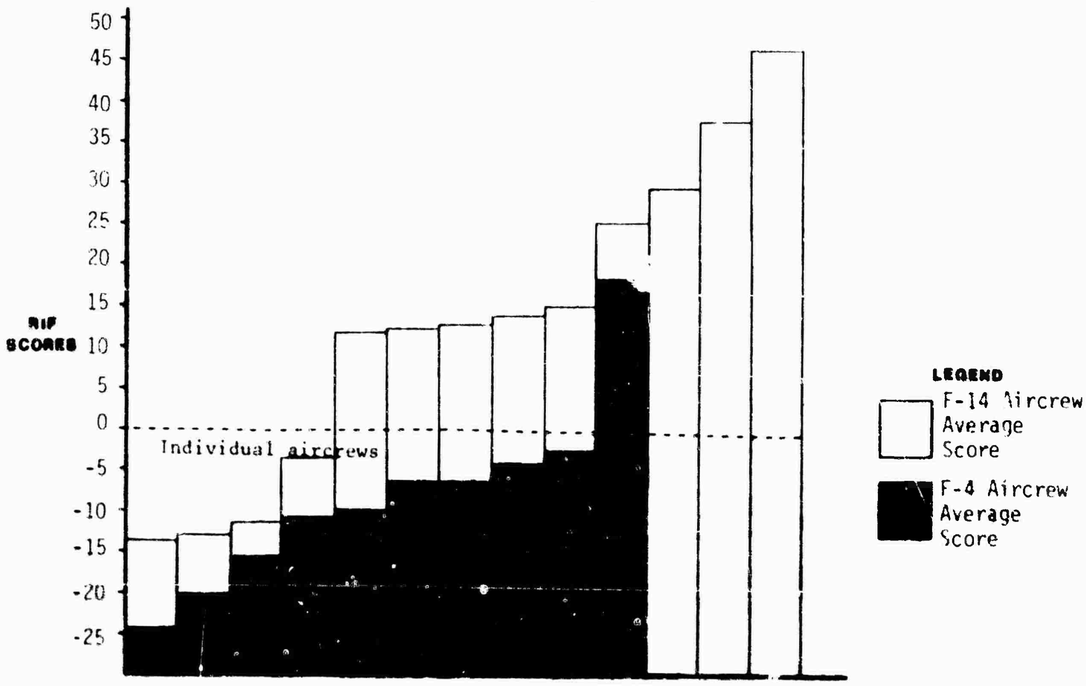


Figure 1. TACTICAL AIRCREW COMBAT TRAINING SYSTEM (TACTS) DATA

A RIF score above zero indicates that an aircraft is relatively more offensive than defensive in relationship to an adversary aircraft. A negative RIF score indicates the friendly aircraft is in a defensive posture. The RIF scores in Figure 1 indicate that, of the ten F-4 aircrews, only one was able to achieve an overall positive offensive average. On the other hand, all but four of the thirteen F-14 aircrews attained an overall positive offensive average.

Aircrews also were ranked according to objective RIF scores and these scores were compared to rankings obtained from adversary squadron pilots, ACM instructor grade sheets, and data from the "Blue Baron" data collection effort conducted on the TACTS range. The latter effort consisted of a combination of objective and subjective data, including parameters such as radar range, system lock-on parameters, visual sighting and kill/miss assessments. In-depth analysis of the type of shots taken revealed that a high percentage of missile shots fired were in the forward hemisphere. Further data analysis revealed that the RIF was not sensitive to forward hemisphere (i.e., all-aspect) missile firings.

ALL-ASPECT MANEUVERING INDEX (AAMI)

As a result of the first data collection, it was concluded that an all-aspect capability had to be incorporated in the RIF. Using the successful elements of the RIF, an All-Aspect Maneuvering Index (AAMI) measurement system was designed and developed for the next data collection series. This series involved data collected from training being conducted on the ACMS, involving participation of a number of F-14 and F-4 squadrons operating out of NAS Oceana.

The AAMI is a measurement system based upon a formula that incorporates range, antenna-train-angle, and angle-off-the-tail as the major variables which define the spatial relationship among interacting aircraft. The formula is weighted by a weapon range modifier which accounts for the influence of individual weapon systems such as the AIM-9L, AIM-7F, and AIM-9G. As with its RIF predecessor, an AAMI score above zero indicates that an aircraft is more offensive than defensive in relationship to an adversary aircraft. A high positive score is awarded when the aircraft achieves an optimal position with respect to the weapons load it has on board. In addition to providing graphical feedback, the AAMI describes a range of numeric indicators such as time to fire, time to first kill, missile type information, number of gun rounds, etc.

Figure 2 contains AAMI summary data from the simulator. All simulator engagements covered in this paper pitted an aircrew experienced in ACM against a computer-driven adversary. The data in Figure 2 reflect differences due to aircraft variables quite similar to the differences shown by previous RIF data collected on the TACTS range. For example, F-14 aircraft consistently outperform F-4 aircraft against adversary aircraft in a simulated environment. The individual differences and performance variations among the three F-4 aircrews and the two F-14 aircrews have been assessed in light of the historical records supplied by each aircrew. One point stands clear from an examination of the data in Figure 2: Post-test scores are much higher than Pre-test scores. This indicates that the training realized from 40 ACM engagements in the simulator does, in fact, improve performance.

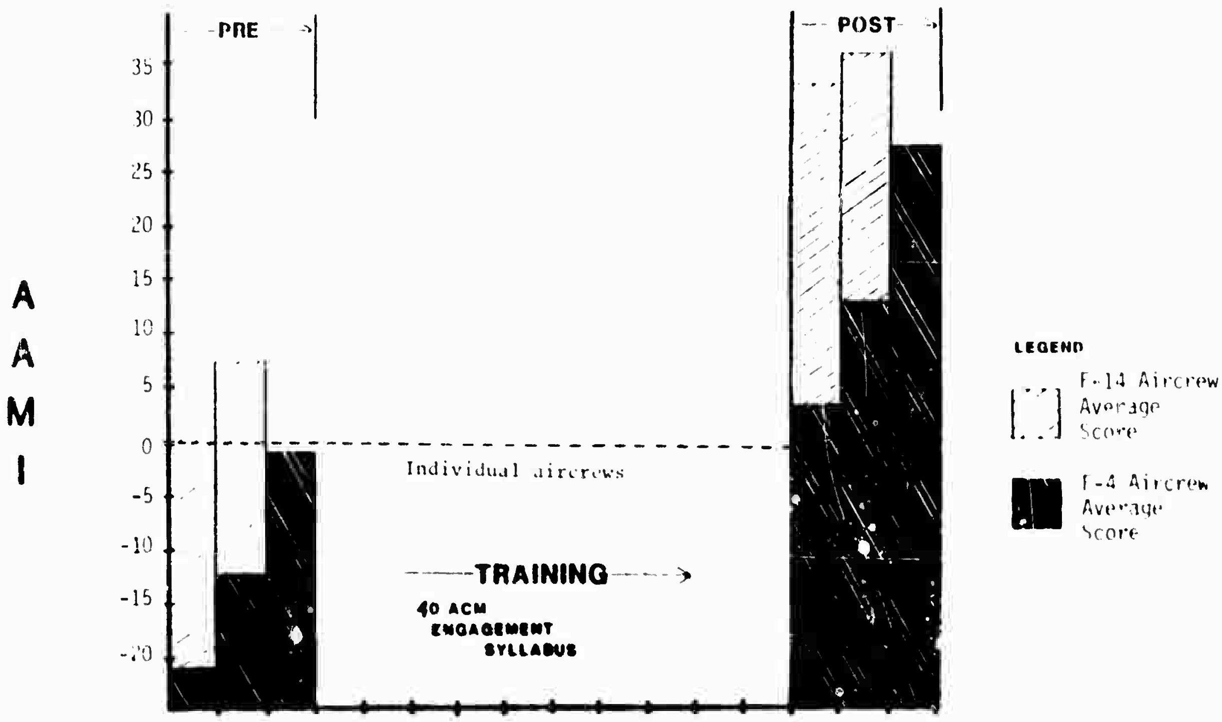
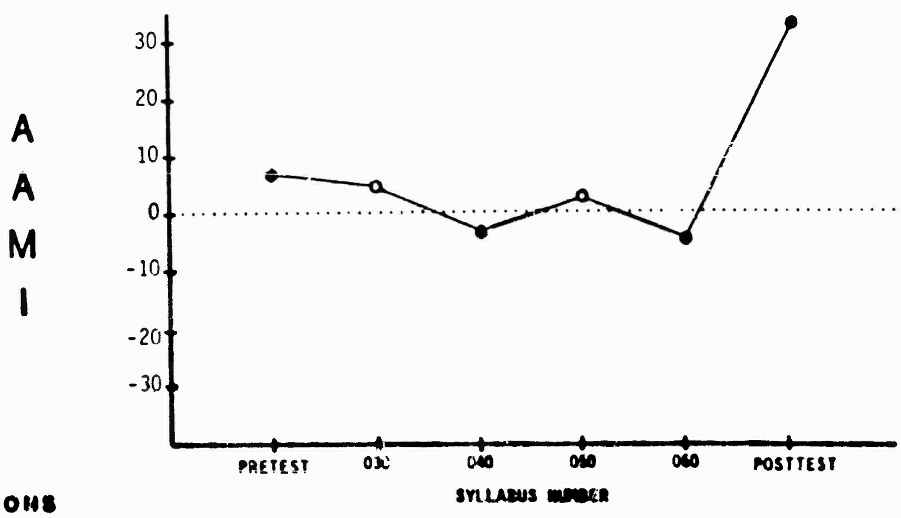


Figure 2. AIR COMBAT MANEUVERING SIMULATOR (ACMS) DATA

Another analysis of F-14 simulator data from the friendly aircraft point of view is contained in Figure 3. The Pre-test data point is an average from seven aircrews over the three engagements comprising the Pre-test. The run conditions and number of engagements experienced were identical for both the Pre-test and Post-test. All simulator runs were stopped when they exceeded three minutes in duration or when 2 successful missile kills were achieved by either the friendly or the bogey. Of significance, Figure 3 demonstrates a substantial increase in performance from Pre- to Post-test. The syllabus numbers in between the Pre- and Post-test represent incremental variations in the training steps applied to the participating aircrews. Each data point in the graph represents the average performance over ten engagements for each syllabus step. The number of aircrews participating, as well as the total number of engagements in each syllabus step, varied across the syllabus due to uncontrollable factors such as aircrew availability and/or simulator equipment problems. The forty engagements experienced between the Pre- and Post-test varied in the level of difficulty presented to the friendly aircraft. As shown in the "run conditions" at the bottom of Figure 3, the first ten engagements in the syllabus (Step 030) had the friendly aircraft loaded with a rear hemisphere missile against a "medium" level of difficulty. A dotted line indicates that no change occured from the previous condition in that syllabus block. Note that a decrease in offensive advantage was registered between the Pre-test and Step 030, during which the friendly fighter lost his 9L all-aspect missile. In addition, during the next ten engagements (Step 040) the adversary difficulty level was increased to "high", which resulted in a drop in the aircrew AAMI average to below zero. That is, moving from a "medium" to a "high" difficulty level opponent resulted in average aircrew performance dropping from an offensive to a defensive posture.

Further analysis of F-14 simulator data contained in Figure 3 demonstrates a substantial increase in performance from Pre-test to Post-test. Switching from "high" difficulty level to "medium" difficulty level when the friendly and adversary aircraft were loaded with similar weapons on the same type of aircraft (both F-14s) resulted in an average offensive advantage for the friendly aircrew as shown by the data point in Step 050. Increasing the level of difficulty from "medium" to "high" while maintaining the same aircraft and weapon relationships resulted in a decrease in average performance below the offensive (zero) score line, once again as shown by the data point for Step 060.

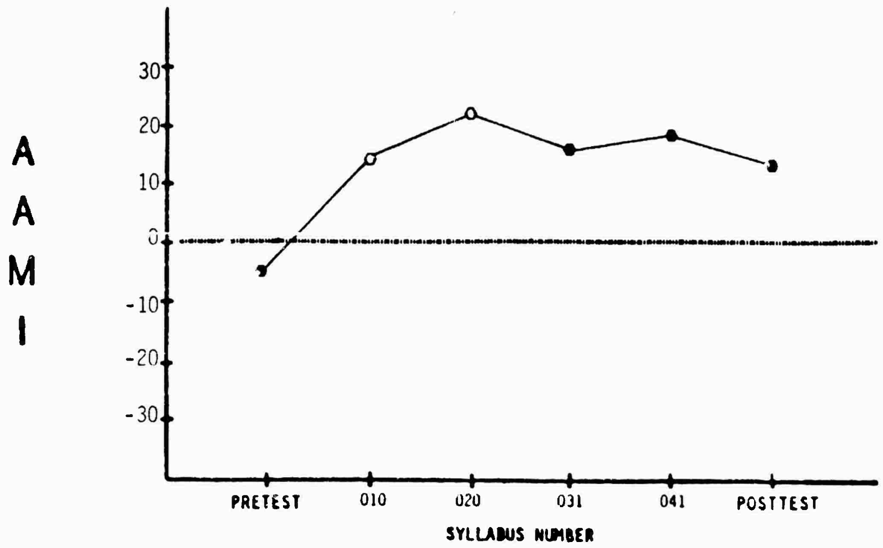
The F-4 data depicted in Figure 4 again indicate that the AAMI reflected relatively high offensive performance in response to an adversary at a "medium" difficulty level when contrasted to performance against a "high" difficulty level. For example, a lower adversary difficulty level at syllabus Step 010, in comparison to the Pre-test, is associated with an increase in the average offensive score. When the high adversary difficulty level is introduced at syllabus Step 031, a performance decrement is noted. The data from the last two syllabus steps and the Post-test data suggest that a learning asymptote may have occurred. Six aircrews participated in the Pre-test; although again the number of aircrews as well as the number of engagements in each syllabus step fluctuated due to uncontrollable factors. As with the F-14 data in Figure 3, the Post-test scores, considered in relationship to the average scores and corresponding standard deviations achieved in other syllabus steps and the Pre-test, suggest that learning has taken place.



RUN CONDITIONS

FRIENDLY WEAPON LOAD	AIM-9L	AIM-9G	------	AIM-9L	------	-------
ADVERSARY TYPE	THREAT 1	------	------	F-14	------	THREAT 1
ADVERSARY WEAPON LOAD	AIM-9G	------	------	AIM-9L	------	AIM-9G
ADVERSARY DIFFICULTY LEVEL	HIGH	MEDIUM	HIGH	MEDIUM	HIGH	-------

Figure 3. F-14 SIMULATOR DATA



RUN CONDITIONS

FRIENDLY WEAPON LOAD	AIM-9L	- - -	- - -	- - -	- - -	- - -
ADVERSARY TYPE	THREAT 1	- - -	- - -	- - -	- - -	- - -
ADVERSARY WEAPON LOAD	AIM-9G	- - -	- - -	- - -	- - -	- - -
ADVERSARY DIFFICULTY LEVEL	HIGH	MEDIUM	- - -	HIGH	- - -	- - -

Figure 4. F-4 SIMULATOR DATA

An examination of a single F-4 aircrew is detailed in Figure 5 as an example of the type of data available from the ACM Performance Measurement System (PMS). The average score is a composite measure which can be easily broken into other types and combinations of metric indicators. In this example, the Pre-test average score is -22.4, while the Post-test performance average increases to +12.29. At the same time, the average engagement length decreases markedly from 184 seconds to 82 seconds from Pre-Test to Post-test. The Pre-test also demonstrates another interesting fact. In the beginning of the session, the friendly fighter lost once but never won a Pre-test engagement. At the end of the simulator training, the fighter won all three Post-test engagements. The initial simulator learning period (Step 010, the first ten engagements after the Pre-test) also reflects the fact that the aircrew was learning the syllabus objectives. As demonstrated in Figure 5, the last five engagements of each syllabus Step (010(2) and 040(2)) resulted in the fighter increasing his average offensive score, decreasing the average engagement length and winning four out of five engagements (one engagement was dropped because of computer problems). The same learning trend is illustrated by the data from the concluding simulator learning period also shown in Figure 5.

DISCUSSION

The data presented in this paper are preliminary in nature. The point of this paper is to bring out the fact that a common, objective measurement tool has been developed for ACM, and that the assumptions underlying the system have been validated via actual aircrew training data.

The ACM performance measurement tool can objectively determine differences in:

- Aircraft Performance (Friendly and Bogey)
- Weapons System (AIM-9L, -9G, -7F, Guns)
- Aircrew (Type and Background)
- Tactics
- Training (equipment, Syllabi)

Examination of the data has been extensive, ranging from initial scatterplots of relevant individual performance points, to variance and correlational analyses to determine the significance of grouped data points and interactions. This examination process, including review by subject matter experts, has verified the validity and reliability of the system as well as the fundamental assumptions of the PMS.

A difficult question is "Does the data collected and analyzed thus far indicate that the air-

			PERFORMANCE AVERAGE		ENGAGEMENTS OUTCOME		
	SYLLABUS STEP	LEVEL OF DIFFICULTY	AAMI SCORE	ENGAGEMENT LENGTH	FIGHTER WINS	THREAT WINS	FIGHTER ESCAPES
PRE TEST	PRE	High	-22.4	184 secs	0	1	0
POST TEST	POST	High	12.29	82 secs	3	0	0
INITIAL SIMULATOR LEARNING	010_1	MEDIUM	13.87	88 secs	1	1	0
	010_2	MEDIUM	30.45	64 secs	4	0	0
CONCLUDING SIMULATOR LEARNING	040_1	High	.71	73 secs	2	1	0
	040_2	High	25.36	68 secs	4	0	0

Figure 5. SIMULATOR DATA F-4 vs. THREAT 1 (example-AIRCREW #18)

crews are learning to fly the simulator?". The answer is that they are, indeed, learning something. The scores improve and the variance decreases in accordance with pertinent syllabus steps and in response to modification in training conditions. Clearly there are "tricks" that can be learned to permit one experienced simulator flyer to beat another simulator aircrew. And, given enough time, some of these tricks may possibly be adapted. For example, it is possible for an aircrew to enhance conditions under which the computer-driven bogey becomes increasingly vulnerable, such as by flying at very high angles of attack or below 200 feet in altitude. However, PSI personnel with ACM experience have been operating and "flying" the simulator for over two years during and before this study. In our opinion, forty simulator engagements, conducted under varying syllabus conditions, does not permit an aircrew enough time to "learn" to trick the simulator. Rather, the data collected thus far and the feedback from the aircrews themselves strongly suggest that more substantive learning is taking place.

A more difficult question is "Do the patterns learned in the ACM simulator transfer to the TACTS range?". The answer to this question is being vigorously pursued. All data collection efforts are being conducted on a not-to-interfere basis. It is difficult to carry out an experimental paradigm on a simulator that is being used for operational training. It is decidely more difficult to apply experimental rigor in the TACTS range environment. Experimental design techniques and statistical controls are being employed to compensate where possible.

Data are presently being collected on the TACTS range as well as from the ACMS to answer both questions. These questions have strong implications for R&D investigations, for training system design efforts, and for combat readiness issues.

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SIMULATION AND TRAINING FOR AIRCRAFT CARRIER LANDINGS

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ABSTRACT

The Visual Technology Research Simulator (VTRS) at the Naval Training Equipment Center was used to study the effects of six factors on carrier-landing training. An in-simulator transfer design was chosen, in which students were trained under various conditions, and then tested under a standard condition that represented maximum realism. The experimental design permitted a relatively large number of variables to be studied, using a relatively small number of student subjects. The subjects were pilots who had no prior carrier-landing experience: 16 recent graduates of Air Force T-38 training, and 16 highly experienced Navy P-3 pilots. Factors investigated were field-of-view, scene detail, platform motion, descent-rate cuing and training task (straight-in approaches vs. circling approaches). Turbulence was included as a factor and pilot type (Navy P-3 vs. Air Force T-38) was also included as a factor to control this source of subject variability. After training under a certain factor-level combination, students were tested on the day, wide field-of-view, circling task with motion and without descent-rate cuing. Results showed that the simulator and training factors generally produced either small differences or no differences at all in transfer effectiveness. There were some advantages of the wide field-of-view and high-detail conditions, but these effects were small and/or short-lived, generally disappearing after a few transfer trials. Training with straight-in approaches resulted in transfer performance that was equal to or better than that produced by training with circling approaches. There were no motion or descent-rate cuing effects on the transfer task.

INTRODUCTION

The Visual Technology Research Simulator (VTRS) at the Naval Training Equipment Center (NTEC), Orlando, Florida is designed for research on flight simulator requirements for training and skill maintenance. The VTRS consists of a fully instrumented Navy T-2C jet trainer cockpit, a six-degree-of-freedom synergistic motion platform and a wide angle visual system that can project computer-generated images onto a spherical screen. The visual system is capable of displaying images via target and background projectors subtending 50 degrees above and 30 degrees below the pilot's eye level and can display 160 degrees of horizontal field.

A major effort at VTRS has involved research to define simulator requirements for the carrier-landing task. There is a need to investigate a large number of visual and other simulator features having substantial cost implications. A research program was planned around the holistic experimental philosophy and paradigm proposed by Simon which stresses the importance of studying as many factors of interest as possible within a single experiment. The first phase of this program consisted of performance studies in which the effect of various simulator components on experienced pilots in the simulator was examined. The second phase consisted of a quasi-transfer study in which the simulator was both the training and the criterion device. Phase three will eventually include a simulator-to-field transfer study involving actual flight tests. This report presents results from the phase two in-simulator transfer-of-training experiment.

The information obtained from phase one experiments was directly relevant to the design of simulators for experienced pilot skill maintenance and transition training. The information from the phase two experiment reported here is relevant to the design of simulators for undergraduate pilot training. The experiment involved pilots with no carrier-landing experience who trained in the simulator under various conditions representing levels of several simulator equipment and training factors. The pilots were then tested in the simulator in its high fidelity configuration. An in-simulator transfer-of-training paradigm was used to study the effects of six factors plus a pilot-type factor on carrier-landing training. A total of 32 pilots with no prior carrier-landing experience were involved in the experiment. Sixteen were recent graduates of Air Force T-38 training and 16 were experienced Navy P-3 pilots.

METHOD

Task

The mission was a daytime carrier approach and landing on the deck of the aircraft carrier Forrestal. The carrier was moving at 20 knots with a zero effective crosswind over the landing deck and 25 knots relative wind down the deck. The mission for this experiment was restricted to include only the final turn of the full circling maneuver as well as the final approach and landing.

Factors and Levels

A large number of factors potentially affecting the carrier-landing cues were tentatively selected as candidates for study. These were pared down by a panel of engineers and psychologists into a set of factors which were investigated earlier in performance experiments. Decisions regarding factors to be included in this in-simulator transfer-of-training experiment were based partly on results from the performance studies. Other considerations were the potential cost impact of factors and the potential training effects and interactions involving factors falling in the category of training aid or type.

"High" and "low" factor level settings were chosen in order to bracket the reasonable range of interest. For the equipment factors, the high levels were generally set at the highest attainable while the low levels were chosen to be the most degraded form of the factor likely to be employed operationally. Other factor levels also bracket the range of interest, but do not necessarily conform to "high" and "low" definitions. A summary of the factors involved in this experiment is given in Table 1.

Field-of-View. The field-of-view high level was a 160 degree horizontal by 80 degree vertical wide-angle display.[14] This wide field-of-view is costly and is representative of that currently available for carrier-landing training only on multi-task trainers such as the 2B35 and the F-14 Wide-Angle Visual System (WAVS). The field-of-view low level was a plus or minus 24 degrees horizontal by -27 degrees to 9 degrees vertical narrow-angle display. This narrow field-of-view is representative of the lower cost Night Carrier Landing Trainers (NCLTs) used for F-4, F-14, A-6, A-7, and S-3 transition training.

Scene Detail. The ship detail for the high detail scene was a daytime solid model computer-generated image (CIG) carrier whose surfaces were defined by 985 edges.[6] The daytime scene included a background seascape colored a uniform blue and a well defined horizon. Brightness levels were approximately 2.80, 0.50, and 0.16 foot Lambert (fL) for the ship, sea and sky, respectively. The detail level was representative of that available from typical daytime CIG systems costing several million dollars. The low level of scene detail was an image of a night point-light CIG carrier consisting of 137 lights. It contained all deck outline, runway, centerline and drop lights. The background was dark with no visible horizon. This display is representative of a night CIG system costing less than a million dollars and used on several Navy NCLTs.

Motion. A six-degree-of-freedom 48-inch synergistic motion platform was fully operational for the high level, and was stationary for the low level of this factor.[ ] This platform is similar to those on the Navy's 27 T-2C Instrument Trainers (device 2F101) used in Undergrade Pilot Training (UPT) except that VTRS computation rates are higher for reduced cuing time lag. While it is representative of many older platforms on existing trainers, it does not have the low noise and improved response of new platforms. An attempt was made to fine tune the operational platform for optimal responsiveness for the carrier landing task by setting gains at 7.5, 2.0, and 1.2 for lateral, heave, and pitch cuing, respectively. Roll, thrust, and yaw cuing gains remained at 1.0.

Approach Type. Pilots performed their training trials with either straight-in approaches or circling approaches. For the circling approach the aircraft was initialized abeam the LSO platform at 5700 feet from the ship and at 600 feet of altitude in the approach configuration (full flaps, speed brake out, hook and wheels down and 15 units angle-of-attack). Fuel was fixed at 3200 pounds to give a gross aircraft weight of 10,000 pounds. A trial consisted of the final turn, final approach and attempted landing.

The straight-in approach was initialized with the aircraft 11,990 feet behind the ship and 4150 feet to the left of the runway centerline. The initial altitude was 400 feet with the aircraft in the approach configuration. The aircraft was trimmed for straight-and-level flight in both initial approach conditions. The straight-in approach was defined specifically to provide task requirements similar to the circling approach but with the ship in view at all times under the narrow field-of-view condition. Thus the aircraft was set to the left of the runway centerline and headed at 18 degrees to the right of the ship centerline heading. (At 25 degrees of aircraft heading relative to ship centerline heading the ship would go out of the narrow field-of-view.) Pilots were instructed to fly this modified straight-in approach straight-and-level out of the initial condition until approaching the runway centerline, then execute a turn and rollout on the runway centerline.

This factor was included in the experiment because of the hypothesis that the daytime mission can be trained adequately with (modified) straight-in approaches. This hypothesis was supported by results presented in [ ] and by preliminary observation. If this hypothesis were true, it could have implications for the field-of-view question since a wide field-of-view is not required to keep the ship visible to the pilot during straight-in approaches.

FLOLS Rate Cuing. The conventional version of the FLOLS display defined one level of this factor. The other level involved the use of vertical bars displayed with the FLOLS which presented glideslope rate of change information to the pilots. This information was presented to the pilots in "command" fashion, that is, the bar height could be interpreted directly in terms of action required to change to the desired vertical velocity. The height of the bars indicated deviation from correct vertical velocity relative to current glideslope displacement and nulled bars indicated correct vertical velocity for any glideslope position. The FLOLS rate cuing factor was included in the experiment on the basis of VTRS work, which indicated a large improvement in glideslope control with rate cuing displays for experienced carrier pilots.[ ] The latter reference (Experiment II) includes a description of the algorithms used to define the command rate bar operation.

Turbulence. Turbulence was included in the experiment at two levels to allow examination of other factor effects under two difficulty levels. The two levels, no turbulence and the highest amount of turbulence under which operations would continue at sea, represent the range of expected real-world turbulence. The main effect of turbulence was also of some interest in this experiment as a training variable. Turbulence was generated in the form of "winds" acting on the longitudinal, lateral, and vertical aircraft axis. These winds were pseudo-random sine waves which were generated

TABLE 1. SUMMARY OF EXPERIMENTAL FACTORS AND LEVFLS

FACTORS	LEVEL SETTINGS "low"	LEVEL SETTINGS "high"
Field-of-view	-27 degrees to 9 degrees vertical, +24 degrees horizontal	* -30 degrees to 50 degrees vertical, +80 degrees horizontal
Scene Detail	Night: point-light ship	* Day: solid surface ship
Motion	Fixed base	* Six-degree-of freedom
Approach Type	*Circling approach	Modified straight-in approach
FLOLS Rate Cuing	*Conventional FLOLS display	FLOLS display with "command" rate cuing
Turbulence[1]	Close to maximum flyable	No turbulence
Pilot Type	Air Force T-38	Navy P-3

*Indicates setting for the transfer test configuration

[1]Turbulence was set at half the "low" level setting for the transfer test.

by the summation of pure sine waves of various frequencies and amplitudes. The RMS values of the winds used were 3.00, 1.25, and 3.00 ft/sec for the longitudinal, lateral, and vertical dimensions, respectively. These values produced a fairly large amount of turbulence judged to be near the limits for safe operation. Frequency and amplitude values used are given in .

Pilot Type. Pilots for this experiment were selected from two populations without carrier-landing experience. One group was made up of recent graduates of Air Force T-38 training and the other group was comprised of experienced Navy P-3 pilots. The pilot group factor was included explicitly in the experiment so that the expected large source of subject variance resulting from differences between the groups could be directly estimated and partialled out of the results.

Factors Held Constant. A number of factors investigated earlier were held constant in this training experiment. CIG images of both ship and FLOLS were used throughout the experiment. The TV line rate was 1025 and engine computations were done at 30 Hz. Visual lag was at the system's optimum 100 msec and the G-seat was off.

Transfer Configuration

After completing their training sessions all pilots transferred to an in-simulator maximum realism version of the daytime circling carrier-landing task. The initial position for the circling approach was the same as that used for circling approaches during training. A wide field-of-view was present along with the daytime scene, motion on, conventional FLOLS and an intermediate level of turbulence. RMS values for the "winds" used during training were halved for the transfer test. This amount of turbulence was judged to be somewhere between small and moderate in size.

Pilots

Pilots for this experiment were volunteers from two populations with no carrier-landing experience. One group of 16 pilots was made up of recent graduates of Air Force T-38 training. All the pilots in this group had approximately 200 hours of total flight time with about 100 hours of flight time in the T-38 in the six months prior to the experiment. The other group was comprised of 16 experienced Navy P-3 pilots. This group averaged 1550 hours of total flight time but varied considerably in overall experience with a standard deviation of 529 and a range of 600 to 2530 flight hours. Experience in the six months preceding the experiment averaged 229 hours, all in the P-3.

Performance Measures

All of the summary measures described and collected in were also collected for the present experiment. Due to space limitations, analyses for only one measure, which essentially summarizes final approach glideslope performance, are presented here. A percent time-within-tolerance measure for the final approach was used to summarize final approach glideslope performance. This score, referred to as the glideslope tracking score, was calculated from 3000 feet to the ramp and used a tolerance band of ±.3 degree. This tolerance was recommended by Navy Landing Signal Officers (LSOs) and represents approximately plus or minus one "meatball" of deviation of the FLOLS display. Results for other scores are discussed, including a wire (longitudinal) accuracy metric for assessing touchdown quality. This score is similar to Brictson's Landing Performance Score (LPS), but it is based on absolute deviation from the desired touchdown point rather than wire catch per se.[·] Touchdowns resulting in a three-wire catch were assigned a score of 100, while touchdowns more than 100 feet behind the one-wire or beyond the four-wire were assigned scores of zero. Touchdowns inside these limits were assigned scores linearly between zero and 100.

Procedures

The experiment consisted of 40 training trials and 16 transfer trials. Before flying any trials, pilots were given approximately one and one-half hours of instruction in carrier-landing procedures in the form of a briefing and an instructional videotape. They then flew two three-minute familiarization flights in the simulator before commencing with the experimental training trials. Instructional feedback was given after each training trial by a VTRS staff member and an "automatic LSO" was used throughout the experiment to give calls during the flights. (A VOTRAX voice generation system was driven by software developed from a modified version of the model described in [1].) Instructional feedback was not given during the transfer test trials.

Experimental Design

A transfer-of-training paradigm was superimposed on the basic experimental design which was an adaptation of National Bureau of Standards, Plan 4.7.16.[1] Each pilot performed 40 training trials under one of the conditions of the basic design followed by 16 transfer trials in the simulator on the high fidelity transfer configuration. The basic design was one-fourth of a fully crossed 2^7 design resulting in 32 experimental conditions and 31 estimable effects.

All main effects are confounded only with three-way or higher interactions as are 15 of the 21 two-way interactions. The other six two-way interactions are confounded in strings of two each and the remaining six estimable terms in the basic design represent strings of three-way interactions. As the basic design was repeated across trials, trial effects are also fully estimable. The two-way interactions judged least likely to be important a priori were assigned to the strings of confounded two-factor interactions. Implicit in the use of this fractional factorial design is the assumption that three-way and higher-order interactions will generally be negligible. Each of the estimable effects in the basic design is also confounded with the subject effects defined by the groupings involved in a particular comparison.

RESULTS

Table 2 presents an analysis of variance summary of transfer test trials for the glideslope tracking score. This analysis estimates effects averaged across all 16 transfer trials which are represented by two blocks of eight trial means. Main effects were tested separately as were the field-of-view by approach type and scene detail by approach type interactions which were considered important a priori. All other estimable interactions were examined individually, but in the absence of strong evidence for an effect, were included in various omnibus terms. The basic "residual" term for an analysis of variance was created from the sum of the two- and three-way string terms. The sum of two-way interactions not involving pilot type and the sum of two-way interactions involving pilot type were tested against the basic residual term. If these effects were not significant, they were combined with the residual term to form a residual estimate against which all other effects were tested. Thus, for example, the F ratios shown for the single degree-of-freedom effects in Table 2 have a 22 degree-of-freedom denominator whose sums-of-squares is from all the indicated sources.

The entire transfer-of-training design may be thought of as a special case of a repeated measures' design with observations repeated on a trials' factor.[1·] In this sense, the residual estimate represents an estimate of subjects within groups error. Trial blocks were tested against a term comprised of all estimable three-way and higher interactions involving blocks which is then an estimate of error within subjects. Two-factor interactions involving blocks were tested omnibus fashion against this same term.

Figure 1 graphically describes the experimental results for the main effects on glideslope tracking performance. The numbers in parentheses in Figure 1 above a block of trials for the effects represent the results of an analysis of variance for that block of trials. The numbers are the ranks of the sizes of the effects (within the 31 estimable effects) of the basic design. Thus, for example, approach type had the largest effect in the first block of training trials, field-of-view ranked fifth, etc. An effect can rank high by chance alone, of course, and such things as stability over time and effect size must also be taken into account when judging the meaningfulness and reliability of an effect. On the other hand, if an effect size does not rank very high, it probably is neither meaningful nor real since it cannot be differentiated from noise.

Table 2 and Figure 1 indicate a large difference between pilot types on the transfer task. This was not unexpected because of the differing flight backgrounds of the groups and there is little interest in this effect per se other than to indicate that this large source of subject variance was successfully controlled. The wide field-of-view results in a sustained transfer advantage of about 6.3 percent more time within ·.3 of the desired glideslope. This effect is the fourth largest in both blocks of transfer trials and accounts for 8.4 percent of the experimental variance on the transfer trials. These results are in the same direction as those obtained in [·], although significance for transfer trials was not obtained in that experiment. Although the field-of-view transfer effect appears real here, it should be mentioned that there was no field-of-view transfer effect on touchdown performance. It is felt that a glideslope effect which is not reflected in touchdown performance should be regarded as small. Thus, in an overall sense, the

TABLE 2. ANALYSIS OF V'RIANCE FOR GLIDESLOPE TRACKING ON ' NSFER TRIALS

Source of Variance	LEVELS High	LEVELS Low	df		Mean Difference[1]		F
Field-of-view	Wide	Nar	1		6.3	(8.4)[2]	6.45*
Scene Detail	Day	Night	1		4.6	(4.6)	3.48
Motion	On	Off	1		3.2	(2.2)	1.65
Approach Type	St. In	Circ	1		2.5	(1.4)	1.05
FLOLS Rate Cue	Cuing	No Cue	1		-3.9	(3.3)	2.49
Turbulence	Calm	Winds	1		2.8	(1.6)	1.26
Pilot Type	Nav P-3	AF T-38	1		-7.6	(12.3)	9.37**
FOV X App. Type			1			(-)	0.49
S. Dtl X App. Type			1			(-)	0.44
2-Factor Int (No Pil)[3]			7	Re-		(9.7)	1.14
2-Factor Int (Pil)[4]			6	sid-		(8.1)	1.10
2 + 3 Way Strings			9	ual		(11.0)	
Blocks (8 Trials)			1		5.9	(7.5)	8.42**
2-Factor Int (Blocks)			7			(7.4)	1.18
3-Factor Int (Blocks)			24			(21.4)	
Grand Mean					34.8		
Std. Err. Difference					2.3		
Std. Deviation					6.5		

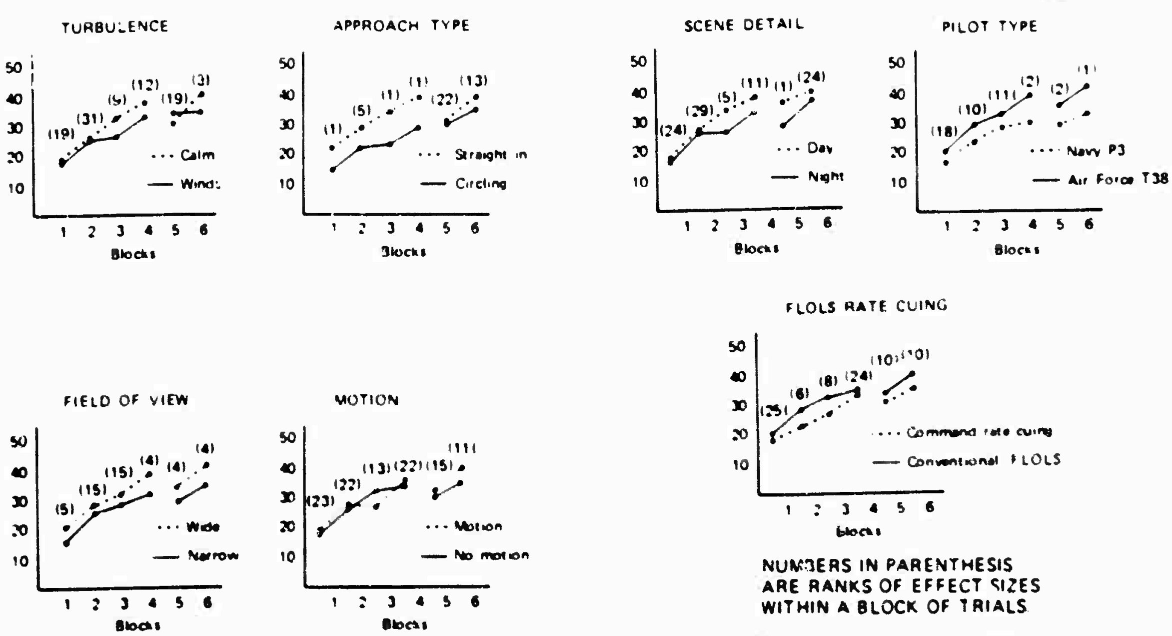
[1]Mean of observations taken under high level, minus mean of observations taken under low level of factor.

[2]Values in parentheses are percent variance accounted for in the experiment. Percents less than 1.0 are shown by a dash (-).

[3]Two-factor interactions not involving pilot type.

[4]Two-factor interactions involving pilot type.

*p < .05
**p ≤ .01



NUMBERS IN PARENTHESIS ARE RANKS OF EFFECT SIZES WITHIN A BLOCK OF TRIALS.

BLOCKS 1 - 4 (Training Trials) ARE 10 TRIAL MEANS

BLOCKS 5 - 6 (Transfer Trials) ARE 8 TRIAL MEANS.

Figure 1. Main Effects for Glideslope Tracking Score: Percent ·.3 of Desired for 3000 Feet to Ramp.

field-of-view impact on transfer performance was not large.

Training on the high level of scene detail results in an initial advantage on the transfer task. As Figure 1 indicates, this is the largest experimental effect on the first block of transfer trials. However, by the second block of transfer trials, this difference has essentially dissipated and the overall transfer effect is not significant, accounting for only 4.6 percent of transfer task variance. No other differential transfer effects were evident, although the approach type effect is noteworthy. Pilots who trained with modified straight-in approaches did as well on the transfer task as those training with circling approaches. This was true despite the fact that the transfer task included a circling approach and those pilots training with straight-in approaches had not flown the circling approach prior to the transfer task. This result is also in agreement with results given in [illegible].

It should be noted also that the FLOLS command rate cuing did not result in a performance advantage, even during training. This is in contradiction to results given in [illegible] which show a large improvement in performance with the rate cuing display for experienced pilots. The pilots in this study were completely novice to the task and apparently did not have the skill level necessary to effectively utilize the rate information at this stage, at least not with the command display mode used here. Most pilots did show considerable general improvement in performance over the length of the experiment, indicating that a great deal of learning was taking place over a wide variety of conditions. The Air Force T-38 group, in particular, had reached an intermediate proficiency level by the end of the experiment, an accomplishment which suggests considerable potential for the simulator as a trainer for the carrier-landing task.

SUMMARY

The following summary of this experiment includes more extensive results presented in [illegible] as well as the limited results presented here. The main conclusion to be drawn from the results is that equipment differential transfer effects were small from a practical point of view. Transfer landing quality was not affected by any factor other than pilot type and approach quality was generally only temporarily affected by equipment factors, i.e., effects had essentially disappeared after eight transfer trials. The only exception to this is field-of-view which did show a sustained effect on glideslope tracking performance. Although final approach effects are important in their own right, approach effects that are not reflected in touchdown performance must be regarded as small. The pilot type effect was generally larger than all other effects combined and the only other factor that had a sizable, sustained transfer effect was a training factor, approach type.

These findings have important implications for simulator design. They suggest that cost and reliability considerations should play the major role in selecting the design for an undergraduate carrier-landing simulator. Simulator hardware advance has apparently reached a stage--at least for the carrier-landing task--where costly increases in fidelity have smaller effects than pilot and training factors and are producing small gains at best. The findings suggest that optimal cost-effective training will occur with a relatively low-fidelity simulator (as defined by the low levels of factors used in this experiment) and judicious use of training variables and schedules.

Individual Factors

A brief summary of results follows with the factor effects listed in the order of estimated overall impact on the transfer task.

Pilot Type had by far the largest effect during the transfer trials but the effect was dependent on the dimension of performance measured. Air Force T-38 pilots did better than Navy P-3 pilots on glideslope tracking and landing wire accuracy, but P-3 pilots did much better on final approach lineup tracking and angle-of-attack control.

The straight-in approach type training resulted in better final approach lineup control on the transfer task despite the fact that the transfer task involved a circling approach. Pilots training with straight-in approaches had 15% more time within the lineup tolerance limit on the transfer task than pilots training with circling approaches. Also, the circling approach training showed no transfer advantage for other final approach scores or landing accuracy.

The wide field-of-view resulted in some advantage on the transfer task for final approach quality but not landing accuracy. There was a sustained effect on glideslope tracking and a temporary effect on lineup and angle-of-attack tracking. The overall effect on final approach quality after eight transfer trials was small at best.

Daytime scene detail training conditions showed no transfer advantage over night scene detail training conditions on landing accuracy. There were transient effects on glideslope and angle-of-attack performance with the daytime training scenes showing the advantage. There appeared to be a lineup performance advantage on transfer for the daytime training scenes but only with straight-in training approaches.

The presence or absence of motion during training did not make a difference on transfer. The addition of rate cuing information to the FLOLS did not result in a transfer advantage compared to training with a conventional FLOLS.

Considerations

Two things should be kept in mind when considering these results. First, as mentioned earlier, subject effects defined by the particular group comparisons were confounded with experimental effects. Although this is true for any transfer-of-training design, the problem is more acute with the one-subject-per-cell design used here in which there was an a priori interest in examining most of the estimable effects. It is very likely that a few experimental effects will be more than trivially biased by subject effects. The subject factor (pilot type) which was included in the experiment did remove a large amount of subject variance and thus reduces this concern somewhat. Further, a covariate task was employed in the experiment (not reported here) which showed some relationship to the criterion task.[15] Taking into account this covariate, resulted in only trivial effect estimate changes for effects of interest. Thus there are grounds for suggesting that subject confounding was adequately controlled, but this problem was not fully resolved.

Second, there is the issue of generalizability of results because of the in-simulator "quasi" transfer of training design. Ultimately, a simulator-to-field study with undergraduate Naval aviators is needed to confirm these results. This study provides recommendations for such an experiment and at the same time depends on a field-transfer study for its own ultimate value. Confirmatory results could go a long way toward increasing confidence in in-simulator results and thus saving some of the enormous expense associated with field-transfer studies.

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A MODEL FOR DETERMINING COST AND TRAINING EFFECTIVENESS TRADEOFFS FOR TRAINING EQUIPMENT*

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ABSTRACT

This paper reports the status of Phase I of an ongoing project to develop a macro model describing the decisions involved in developing training equipment. The purpose of the model is to assist managers in making such decisions by providing information concerning the tradeoffs between cost and training effectiveness caused by different configurations and choices of equipment. After the development of a preliminary model, field research was conducted to determine the feasibility of testing such a model and to collect information to expand the preliminary version into a more pragmatic tool.

Results of the field work led to several conclusions. First, many of the types types of data needed to validate such a model are available, hence making such a project feasible. Second, an examination of the available data led to an expansion of the preliminary model to include training value of the various trainer characteristics. Third, much work is needed to develop longitudinal data bases of job performance before sound predictions can be made concerning the impact of trainer characteristics on technician performance after graduation.

PURPOSE

This paper reports the status of an ongoing project to develop a macro model to assist managers in making decisions concerning training equipment. The model is designed to permit comparisons of alternative equipment and configurations, and the associated cost and training effectiveness for the alternatives. The project was designed to meet the three objectives listed below:

(1) To develop a macro model for use in making cost/benefit tradeoffs between the various characteristics that may be utilized in training equipment, and to give both military and industry guidelines to justify decisions relating to trainer design.

(2) To determine the efficiency of a sample of trainers currently in use.

(3) To determine the relative cost and training effectiveness of various characteristics or capabilities that can be used in training equipment.

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BACKGROUND

The operational readiness of sophisticated military systems depends, to a great extent, on the skills of the technicians who maintain those systems. As the sophistication of current military equipment increases, the operational training for the use of such equipment becomes simpler. Conversely, the training of technicians to maintain the equipment becomes an even more complex task (1). In order to assist in the training of maintenance personnel, therefore, the Armed Services are increasingly relying on the use of maintenance trainers and simulators (2).

There are two basic reasons underlying this trend. First of all, it is assumed that training devices are capable of training a student at least as effectively as instruction which only utilizes actual equipment. In fact, research in instructional psychology suggests that the use of actual equipment for training purposes may be less efficient and effective than the use of training devices which permit greater latitude in material presentation (3). For example, a training device can be designed so that an overall task is broken into smaller, less complicated subtasks which can be more readily grasped by a student. In theory, this leads to a better eventual mastery of the whole task (4). Training devices also allow students to practice and observe procedures which, although necessary for competency, are potentially too dangerous in terms of personnel and/or equipment safety for the neophyte to perform in the training environment (5). Finally, training devices are assumed to provide more efficient training due to their built-in capabilities which allow automatic student monitoring, decreased instructor demand for routine problems, and increased student experience and practice (6).

The second reason why training devices are becoming increasingly popular is that such devices are often assumed to be more cost effective than the use of actual equipment (7). The use of actual equipment in training situations is expensive in terms of such factors as fuel costs, equipment wear and tear or damage, and loss of availability for operation while diverted to training use. Therefore, even when the training effectiveness of a course utilizing a training device is only equivalent to that of a course utilizing the actual equipment, if the device is less expensive to acquire and run than the actual equipment, it is a better value for training purposes.

Although such reasons for using training devices are seductive in theory, these assumptions have not necessarily been found to be true in practice. Therefore, the question that arises is whether or not training devices are effective --either in terms of cost or training -- when compared with more traditional training methods. The principles of learning psychology have been found to fail short when practiced in military training situations (8). Many of the "common sense" characteristics often included in the design of training devices (e.g., high realism) have not been found to be consistently effective (9,10). Furthermore, although the primary goal of training is to produce qualified technicians more quickly, only one study has been performed to comparatively evaluate the effectiveness of technicians trained with actual equipment versus those trained using simulators. No differences were found between groups in this study (11). Virtually no research has been conducted relating life cycle costs to training effectiveness.

The lack of hard facts concerning the usefulness of various trainer characteristics makes training device justification and design tradeoffs difficult. Because of this, decisions are made based only on cost factors since there are no data available to evaluate training value. Therefore, both the Services' project managers and industry have been unable to articulate requirements for training devices in terms of projected training value. Equipment for training is often proposed, developed, and procured without an estimate of the expected training effectiveness and without a thorough analysis of which tasks are suited to the use of a training device or simulator. Such practices, however, mean that the creation of an optimally effective training device is only serendipitous.

Since effective training is vital for the development of the skilled technicians who are a key link in the chain of operational readiness (12), it is necessary that incompatibilities between current assumptions and actual data be identified and rectified. There is, therefore, a strong requirement that training efficiency and effectiveness be considered along with costs during the front end analysis and design of new maintenance training equipment. The formulation of consistent and effective policies for such designs depends to a great extent on the use of cost and training effectiveness data in a model of logistics, manpower, personnel, and training. The projections of such a model must be further clarified and validated using hard data collected from the field.

Two sets of factors must be dealt with in such a project: economic considerations and training quality. Historically, cost analysis has been accomplished for tradeoffs between actual equipment and simulators used for training. Cost considerations have been based on investment costs and efficiency items such as expected fuel savings. However, experience with successful training devices indicates that certain efficiencies which can also be assigned a dollar value accrue once the trainer is fielded. Examples of these are time saved in training, operational equipment made available for missions other than training, lowered investment costs, reduced maintenance costs, and less run time on operational equipment. Such potential efficiencies should be identified and developed into an economic model for use in prediction of life cycle costs during front end analysis.

The second set of factors which must be considered in such a project deals with differences in training effectiveness between courses using training devices and those using the actual equipment. Often the assumption is incorrectly made that if a training device is less expensive than the actual equipment as used in training, it is a better buy, and, therefore, should be used. This line of reasoning is specious. In order to justify the use of a training device, it is fallacious to consider only the costs of acquiring and maintaining it. Attention must also be focused on how well each facilitates student learning, and on the resulting benefit of more quickly producing qualified technicians. While effectiveness is not easily quantifiable, there are enough indicators to believe that, at least in gross terms, it can be measured and modeled. Such information would be helpful in making sound management decisions on the value of simulators for training.

The evaluation of the cost and training effectiveness of maintenance simulators and trainers is not a new idea. In past studies, investigators have typically examined variables such as acquisition costs and training effectiveness in the school setting (13). Military training, however, is intended to prepare personnel to perform various jobs in operational units. Therefore, the true measure of effectiveness is actual job performance rather than performance within a training course. Similarly, although comparisons between acquisition costs of training devices versus other training methods are an important consideration, it is also necessary to consider the comparative life cycle costs of these methods before an informed decision can be made. Such an examination must be accomplished over a broad spectrum of applications before an ultimate criterion of training program effectiveness can be established or predicted.

Two types of tools are necessary in order to make sound, knowledgeable decisions during the development of maintenance trainers. The first of these tools is a macro model which can be used as a high level filter in making design decisions and determining device justifiability. This type of model would act as a decision screen, specific only enough for early decision making by program managers. Concomitant with such a decision screen, a more specific, pragmatic design screen must also be developed. This type of tool could be used effectively both on a lower level in DoD and in industry for making specific cost/training effectiveness tradeoffs in the design of future training devices.

PHASE I: FIELD STUDY

Phase I of this project was designed as a pilot study to identify potential efficiency and effectiveness factors, and to develop a prototype model with them. Maintenance trainers were chosen for analysis in this phase of the study for the following reasons:

(1) Cost indicators and potential savings are not obvious as in the case of flight simulators where flying hours have a known cost. Thus, the study avoids the issues of expressing cost avoidance as an efficiency, and permits a focus on more subtle cost savings as well as highlighting concern on effectiveness issues.

(2) Instances exist in maintenance training where individuals in the same skill and weapon system were trained in different ways -- some with actual equipment and others with training devices. This situation allows the collection of control data better suited for making judgments of the relative cost and training effectiveness of courses using training devices versus those which do not.

(3) The factors leading to the design of an effective maintenance trainer are much less well defined than for operator trainers. Therefore, if the characteristics leading to effective design can be determined and put into a model for maintenance trainers, it is probable that attempts to generalize such a model would be much less difficult than if the model were first developed for operator trainers.

(4) Emphasis on ways to enhance maintenance training to offset design, support, and manpower problems has forced DoD to look at ways to improve and expedite support training. Selection of maintenance trainers for this work is consistent with the DoD emphasis to improve training for maintenance.

Preliminary Model

As discussed earlier in this paper, in order to develop a valid tool to make knowledgeable decisions concerning device cost and training effectiveness tradeoffs, four levels of variables must be considered:

(1) Training effectiveness in the school,
(2) Training effectiveness in the field;
(3) Acquisition costs of equipment;
(4) Life cycle costs of equipment.

However, although necessary in the creation of such a tool, these factors are not sufficient in and of themselves. There are also several modifying variables which, although not directly relating to device effectiveness, act as filters integral to any comparison between the effectiveness of a training device versus the actual equipment (Figure 1). First of all, the goals of various maintenance training programs differ, and the principles of instructional technology do not lend support to the supposition that the same type of training will be equally efficient for all purposes. (For example, if the goal is to teach the student motor skills such as performing a task requiring interactive analog inputs, one would probably not depend wholly on a verbal explanation -- without hands-on practice -- to teach such a task.) Therefore, in order to compare the relative effectiveness of training programs, it is important to keep in mind the objectives toward which the learning situations are aimed. A second filter which must be considered in the creation of such a model is the characteristics of the students being taught. For example, in teaching a low level student with vitually no experience or knowledge in the subject area it would be necessary to go into much more detailed explanations of the subject matter than when giving a review course to students who had been performing the same task for over a year. A third filter which one must be aware of in facing such comparisons is the characteristics of the instructor teaching the course. For example, if an instructor does not understand or like to use a particular technique for teaching, he or she will not utilize the method as well as an instructor who does.

Therefore, although comparing the relative effectiveness of maintenance trainer equipment and actual equipment training is theoretically a straightforward task, it is important to consider these modifying variables --program goals, student experience and aptitude, and the instructor experience and aptitude -- in order to meaningfully interpret any results of such a comparison (Figure 1).

This framework was used as a preliminary paradigm to describe the field of training device cost and training effectiveness factors. The Phase I field study was then designed to test the effect of the independent variable of training method on the four levels of device effectiveness, taking into account the modifying variables discussed above. The objectives

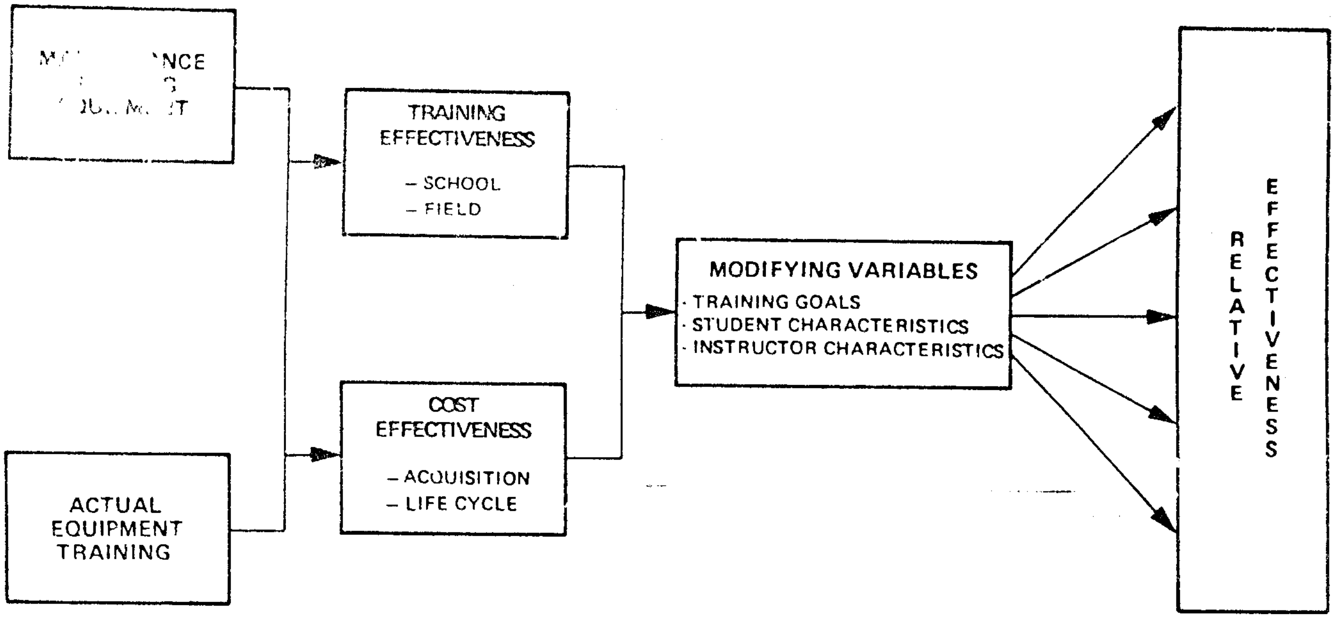

Figure 1. Paradigm for Determining Relative Effectiveness of Two Training Methods

of this field study were to collect information to develop this initial paradigm into a testable model, and to determine the feasibility of collecting data to test the model.

Methodology

To help achieve these objectives, two sets of data collection instruments were developed. The first of these was a set of Behaviorally Anchored Rating Scales (BARS) which were used to assess technicians' performance in the the field. In order to develop these scales, instructors in the role of subject matter experts were asked to create a series of critical incidents describing behaviors which differentiate between a good technician and a poor one. These incidents focused on specific technician actions closely related to the job, and differentiated between success and failure as a maintenance technician. Several hundred of these incidents were collected, thematically analyzed, and placed into scales. They were then rated by the instructors on a seven-point scale with the scale value of 1 being very poor performance behavior and the scale value of 7 being very high performance behavior. Those incidents with the lowest standard deviations and means closest to 1 and to 7 were then placed on a graphic type rating scale to be used as behavioral anchors for the scale.

There are two advantages to using BARS. First, the description of the scale points is written in terms that can be easily understood by the raters. Second, since the type of person who developed the scale is also the type of person who uses the scale, the raters have a vested interest in using the scales correctly (15).

The use of the BARS development technique in this study yielded seven specific scales:

1. Safety: Behaviors which show that the technician understands and follows safety practices as specified in the technical data;

2. Thoroughness and Attention to Details: Behaviors which show that the technician is well prepared when he arrives on the job, carries out maintenance procedures completely and thoroughly, and recognizes and attends to symptoms of equipment damage or stress;

3. Use of Technical Data: Behaviors which show that the technician properly uses technical data in performance of maintenance functions;

4. System Understanding: Behaviors which show that the technician thoroughly understands system operation allowing him to recognize, diagnose, and correct problems not specifically covered in the Technical Orders and publications;

5. Understanding of Other Systems: Behaviors which show that the technician understands the systems that are interconnected with his specific system and can operate them in accordance with technical orders;

6. Mechanical Skills: Behaviors which show that the technician possesses specific mechanical skills acquired for even the most difficult maintenance problems; and

7. Attitude: Behaviors which show that the technician is concerned about properly completing each task efficiently and on time.

These seven skills were found to be generic, holding true for both systems ultimately chosen for this study phase.

The second data collection instrument was a series of questionnaires for students, instructors, and technicians. These questionnaires were designed to collect two types of information: (1) demographic information on subject background, training, and experience; and (2) subjective information such as subjects' attitudes toward training devices in general, and their perceptions and evaluations of the specific device with which they were working.

For this phase of the study, the F-16 and E-3A AWACS Navigation Maintenance trainers were selected to serve as the data sources for the development of the preliminary model. These trainers are two of the most recent examples of maintenance trainers in the field. The F-16 trainer consists of a series of six freeplay systems designed to assist in teaching maintenance courses in the flight controls, Comm/Nav, electrical systems, engine start, engine diagnostics, and engine run for the F-16 aircraft. The AWACS device is a procedural trainer designed to be used in courses in navigational system maintenance.

Data for this phase of the study were collected from subjects who had used these two training devices, and also from control subjects who had gone through the same courses without using the training devices. The training effectiveness soft data were collected using the three versions of the questionnaire to gather background data concerning the subjects and their opinions of training courses and devices. The BARS were used to determine the instructors' performance appraisals of those students having just completed the course and of those having previously taken the courses. Supervisors' performance appraisals were obtained for technicians having recently graduated the courses, and for those who had previously graduated the courses. This redundant use of the BARS was done in order to help determine the validity of such subjective judgments, and to partially ascertain the relationship between judgments of technician performance at the school and field levels.

Hard data of training effectiveness were collected through student course test scores and Work Unit Code (WUC) information. WUCs yield hard data concerning group and individual level technician performance in the field in such areas as removal time, repair time, retest OK (RETOK) rates, etc.

Data concerning the acquisition and life cycle costs for courses utilizing and not utilizing the trainer were also collected through the Air Force and the contractor. These field study data are summarized in Tables 1 and 2. Missing data in the tables result from the normal vicissitudes of subject availability encountered in a field study of this nature.

Table 1. Data Collected in Phase I Field Study

TRAINING EFFECTIVENESS STUDY			
School		Field	
F-16	AWACS	F-16	AWACS
Soft Data	Soft Data	Soft Data	Soft Data
• Instructor Interviews	• Instructor Interviews	• Technician Interviews	• Technician Interviews
• Student Interviews	•		
• Instructor Questionnaires	• Instructor Questionnaires	• Technician Questionnaires	• Technician Questionnaires
• Student Questionnaires	•		
• Instructor's Performance Appraisal of Student (BARS)	• Instructor's Performance Appraisal of Student (BARS)	• Supervisor's Performance Appraisal of Technician (BARS)	• Supervisor's Performance Appraisal of Technician (BARS)
Hard Data	Hard Data	Hard Data	Hard Data
• Test Scores	• Test Scores	• Work Unit Code (WUC's) Information	• Work Unit Code (WUC's) Information

Table 2. Data Collected in Phase I Field Study

COST DATA			
Acquisition		Life Cycle	
F-16	AWACS	F-16	AWACS
Hard Data	Hard Data	Hard Data	Hard Data
• Developmental Costs	• Developmental Costs	• Consummable Materials	• Consummable Materials
• Equipment Costs	• Equipment Costs	• Rate of Revision	• Rate of Revision
• Instructor Training Costs	• Instructor Training Costs	• Equipment Maintenance Costs	• Equipment Maintenance Costs
• Instructor Preparation Time	• Instructor Preparation Time	• Equipment Availability	• Equipment Availability
• Area Requirements	• Area Requirements	• Life Span of Equipment	• Life Span of Equipment
		• Fuel/Support Equipment Costs	• Fuel/Support Equipment Costs
		• Instructor Preparation Time	• Instructor Preparation Time

Revised Model

Although it was recognized during the construction of the preliminary model that trainer characteristics are an important variable directly impacting the effectiveness of training devices, a comprehensive list of these characteristics could not be developed until the views of the users were collected and the impact of the various charateristics on effectiveness were observed. This information showed that by and large the greatest "need" perceived by users was for high "realism". As stated earlier in this paper, training literature does not totally support such a statement of need. However, after close examination of the data, it was found that the discrepancies between the findings in the literature and the "universal" statements by the users were to a great extent a result of the lack of a consistent definition for the term "realism". For example, when one instructor stated the need for high "realism" in the design of an engine trim box to teach a motor skill, he was not necessarily referring to the same device characteristic as an instructor asking for high "realism" of engine sounds. As a result, the characteristic of "realism" was replaced for the purposes of this model by the taxonomy listed below.

1. Static Realism

   a. Visual Realism: The extent to which the device components or subsystems appear to be the same as on the actual equipment.

   b. Spatial Realism: The extent to which the device components or subsystems are physically situated as on the actual equipment.

   c. Auditory Realism: The extent to which the device components or subsystems approximate the sounds of the actual equipment.

   d. Kinesthetic Realism: The extent to which the device components or subsystems approximate the feel of the actual equipment.

2. Dynamic Realism

   a. Temporal Realism: The extent to which the reaction time and response of the device components, or subsystems approximate the actual equipment.

   b. Extent of Simulation: The extent to which the device as a system approximates the total responses of the actual equipment rather than only following the responses given in the technical data.

The other training device characteristic which many users felt was important to consider was computer aided instruction (CAI). This too appeared to be a taxonomy rather than a single variable:

1. Student Aids: Those computer managed functions which directly aid the student to learn the material.

2. Instructor Aids: Those computer managed functions which indirectly aid the instructor in teaching the student the material.

3. User Aids: Those computer managed functions which facilitate the student's use of the training device.

Based on these taxonomies and the information collected in the field, the preliminary model was revised to expand the description of the parameters to be considered in the design and development of a training device. (This revised model is graphically depicted in Figure 2.) The subjective data collected supported the hypothesis of the influence of modifying variables on training effectiveness. Of the three original modifying variables considered, support was found to justify further investigation of the effects of both student characteristics and training program goals on training effectiveness. Information about these two characteristics consistently suggested that "lower level" students --where this is defined by skill, knowledge, or experience -can best be taught using different techniques than those used for "higher level" students. Similarly, the data suggested that different sets of device characteristics would best be utilized in teaching different program goals (e.g., mechanical skills or theoretical troubleshooting).

The attitudes of an instructor toward a training device, however, (although logically related to how well the device is used by the instructor and how well the student uses and learns from the device) were not found to significally impact training effectiveness in the sites and programs investigated in Phase I. In the two programs studied, the instructors as a whole were rather ambivalant towards the devices when they first began to use them, but they became more positive as their experience with the devices increased. Although this may cause differential effects in training between students taught directly after trainer acquisition as opposed to those taught later, the effects of this variable appear to be equated over a period time. A lesson to be learned here, however, is that improved instructor training immediately following the fielding of the training device can positively impact the acceptance and use of the device.

Although the modifying variables mentioned above have significant impact on the quality of training and must be considered in the interpretation of effectiveness data, the characteristics of the device itself are of superordinate importance in their effect on cost and training effectiveness. For the purpose of this model, "effectiveness" is defined as a relative term. Since training effectiveness cannot currently be judged on an absolute scale, it must be examined through a comparison between the quality of technicians in the field who have been taught using a training device versus those who have not. The relationship of these characteristics to the overall model is represented to the horizontal "slice" depicted in Figure 2. In Figure 3, one of these "slices" has been rotated 90 degrees in order to give a clearer view of its components.

At this level, the model can potentially aid in making more pragmatic decisions concerning the design of training devices. Given a sound definition of training device cost (as defined both by acquisition and life cycle costs), and the establishment of a sufficient data base, it will be relatively easy to determine the cost associated with different training device designs under consideration. For example, in low quantities, those characteristics defining static realism are relatively low in cost as opposed to those characteristics defining dynamic realism. The missing factor in the design and development considerations of today, however, is the concomitant consideration of comparative training effectiveness. By developing a large enough data base, it will eventually be possible to generate a series of equations which will allow managers to make decisions as to the relative training effectiveness of various alternative design configurations under consideration. It will then be possible to determine not only the cost of acquiring and using a training device, but also the training effectiveness of such a device relative to the actual equipment. For example, in Figure 3, for a certain training goal and student level there are hypothetically two different configurations which could be used in the design and development of a trainer, both of which would be equivalent to each other and to the actual equipment in terms of training value. The recommendation would then be to either use the more cost effective of the two alternatives, or to increase the projected level of training effectiveness by selecting a device configuration higher on the Y-axis.

The development of this paradigm into a useable tool for managers depends upon the creation of performance measures to determine the training value of various design characteristics. Once this is accomplished, tradeoffs between cost and training effectiveness can be determined. It should be recognized that the design characteristics for a training device or simulator are the driving factors in effectiveness potential and are also the major determinants of the ultimate cost. This leads to the conclusion that cost and benefit tradeoffs can be made for design characteristics once the manager determines specific training objectives. It will then be possible to approach the larger question of comparing cost and training effectiveness in order to make a rational choice between equipment alternatives.

PHASES II AND III: MODEL REFINEMENT AND VALIDATION

The model as described above was developed using two maintenance trainers. Before it can be considered as a viable instrument which can be applied to other maintenance training devices it must undergo validation and refinement. To do this, it must be ascertained whether the parameters of the model validly apply to other maintenance training device systems, whether the indicators of cost and training effectiveness are meaningful for the evaluation of maintenance training devices, and whether the design characteristics included in the model significantly impact the usefulness of the device in terms of these indicators.

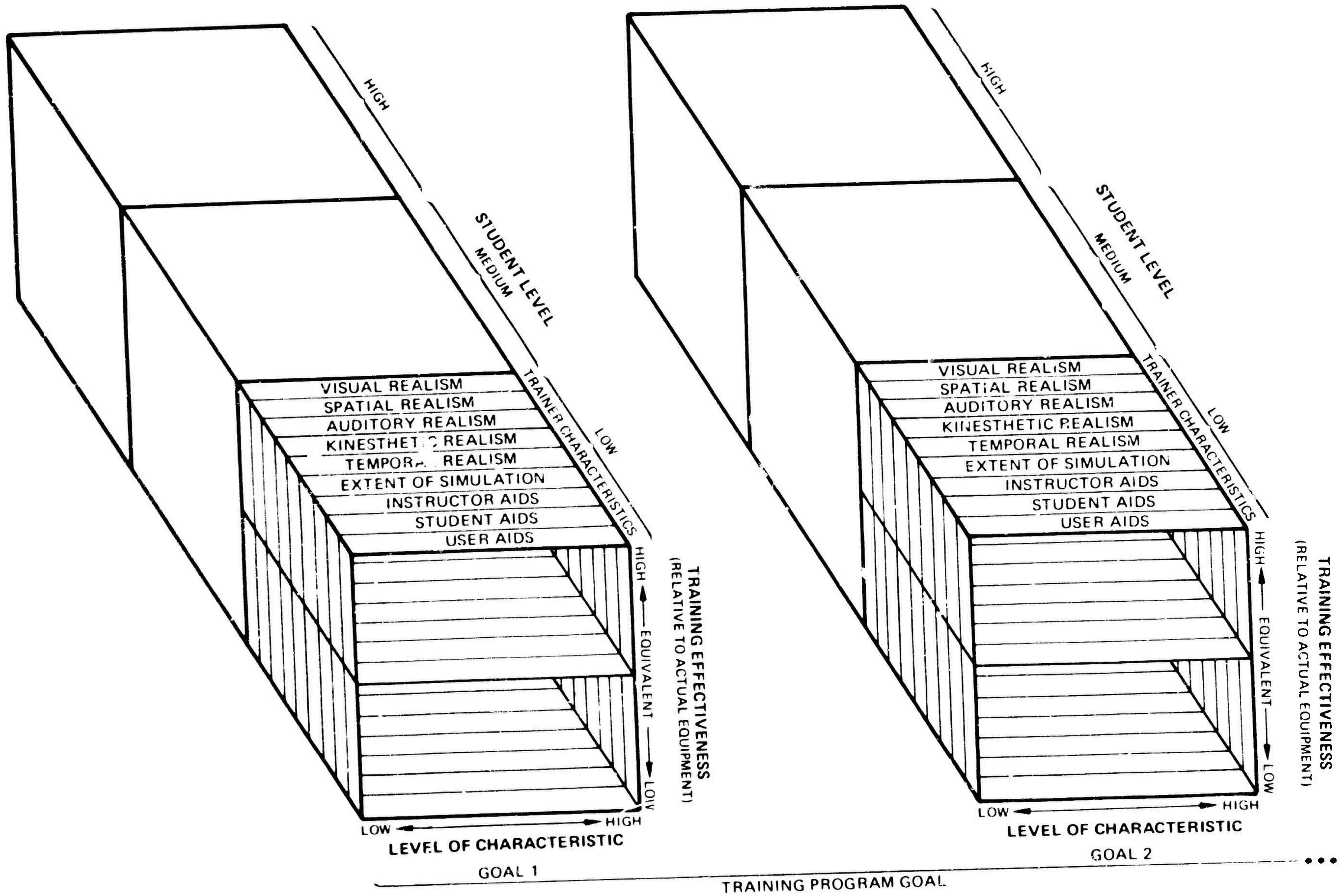

Figure 2. Revised Model for Determining Relative Effectiveness of Two Training Methods

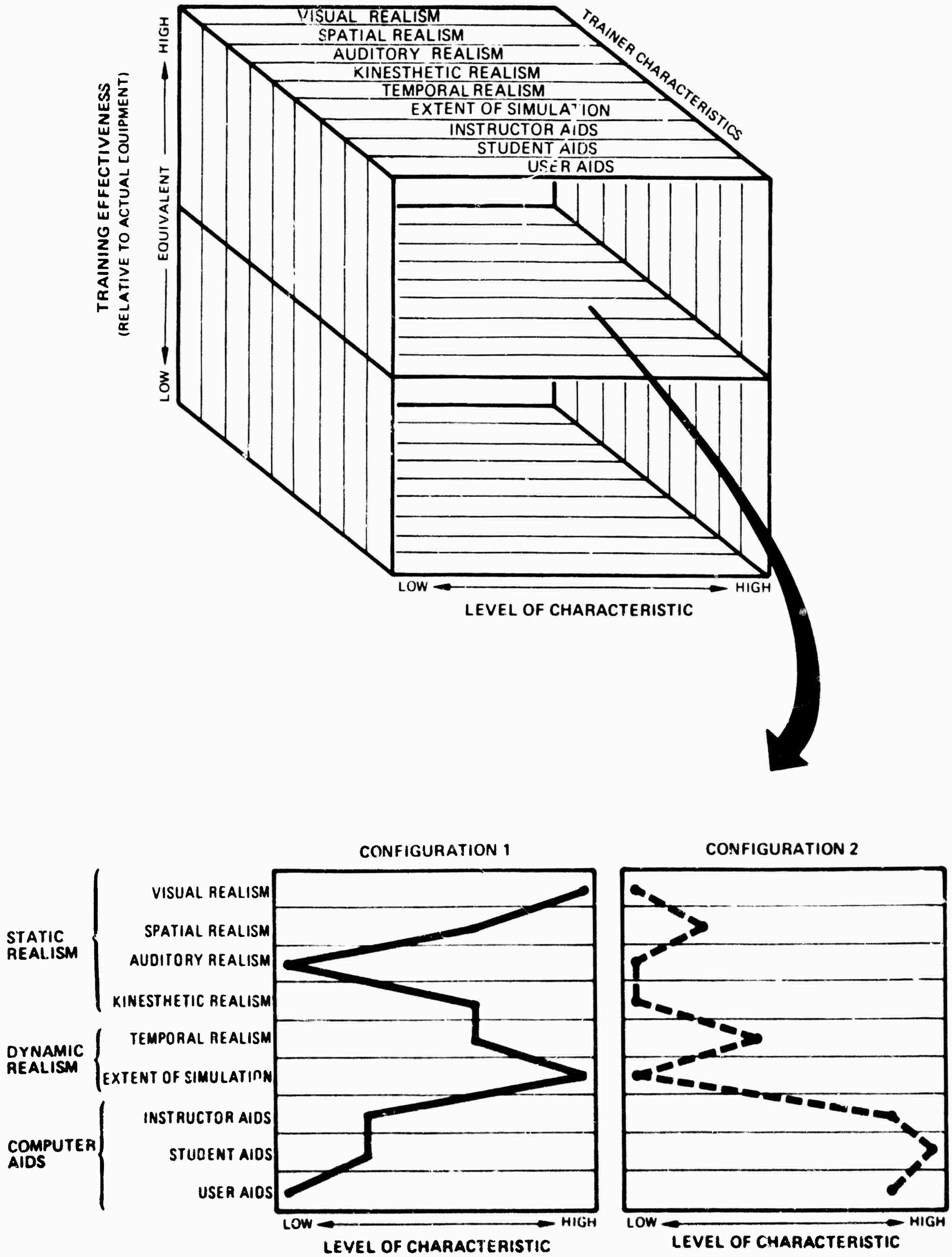

Figure 3. Detailed View of Revised Model

Although this model has intuitive appeal, it cannot be used until it is validated. In the future, it will be necessary to collect longitudinal data along various points of the characteristics continua and relate these to both cost and training effectiveness. Such a validation must be longitudinal, to say the least, and is outside the scope of the present study. Validation at this point in time will consist of collecting comprehensive data on the training systems currently in the field. The systems will be rated rated and placed on the characteristics continua, and used as inputs for the model validation and refinement.

The next step will be to collect data from courses using maintenance training devices and their concomitant control courses. These data will be analyzed in terms of the structure of the model to test for goodness of fit. The model will then be refined in order to better account for all data based on any mismatches in the comparison. Once the model has been refined in Phase II, it will be further validated using a broader spectrum of training devices and simulators. Much is already known about requirements for development and design of an effective operator trainer. Phases I and II of the current study will offer significant parallel data for maintenance trainers. This information will be synthesized and validated for the creation of a generic model in Phase III.

Several types of questions are to be answered in Phase III. If the indicators of cost and training effectiveness are found to be valid for maintenance trainers, are they equally valid for operator and crew trainers? Do these indicators apply equally well to part task training devices and to system devices? These kinds of questions must be answered over time before the model can be thought of as a univeral tool to be used by management.

During the Phase III validation, each service will be asked to apply the model throughout development and acquisition of an emerging system. Use of the model during this phase will be controlled only to the extent that each element of the model must be investigated. (Conditions may exist where one or more of the elements may not apply to the chosen system. It is important, however, that as much information as possible be collected concerning all parameters.)

The prediction of performance data will clearly be the most difficult to validate. This is compounded by the fact that not enough attention has previously been given to the systematic gathering of such information. As a result, there is a lack of a sufficient data base. Job performance data for the two systems investigated in this study were limited to a comparison of WUC items, time to repair, RETOK rates, etc. Other performance measures were subjective. Since the purpose of collecting these data was to establish their usefulness as indicators of effectiveness rather than to evaluate trainers, their use for this phase was acceptable. In the validation phase, however, it is reasonable to estimate probable effectiveness gains on emerging systems from using performance data from existing systems. These estimates could then serve as a basis for selecting design features and justifying design decisions.

DISCUSSION

The model presented above was prepared as an archetype, showing examples of the types of considerations which need to be made in the creation of training devices. Such considerations will aid in making knowledgeable decisions relative to cost and training effectiveness during device development and design. Although the model is empirically based and analytically developed, it is not without shortcomings which primarily reflect the state of maintenance training the Armed Services tod.

The concensus of field ersonnel is that training courses such as t se being studied in this project are of insignif nt value to training except for use as a gener verview. Rather, many people feel tnat the mos aluable training is done during on-the-job training (OJT). This assumption is partially supported by the previous literature in which no differences are found between the performance of students having been through courses using actual equipment and those who went through courses using a training device. As stated in the introduction to this paper, one of the shortcomings of this research is that the focus has been primarily on effectiveness vis a vis the school situation rather than the actual field situation. However, the very structure of maintenance training in the Services supports this assumption: students are taught basic information in the school and more specific information through either formal or informal OJT upon graduation. Therefore, all technicians will eventually reach a minimum standard of qualification for the job: if not, they will be moved into a different job classification. As a result, the question is not how effective is the training, but rather how quickly does the student reach the level of minimum qualification (Figure 4).

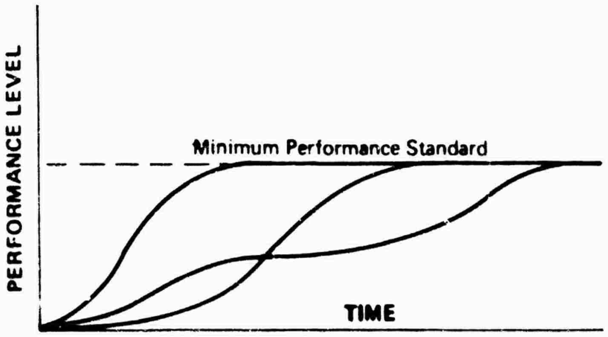

Figure 4. Comparative Rates with Which Various Training Courses Prepare Students to Meet Minimum Standard of Performance

Such criterion-referenced measures of training effectiveness may no longer be appropriate since the advent of training devices. It is not safe to assume that because a training course has been taught in a classroom using actual equipment as an adjunct, that a training device must be designed to fit this mode. This, coupled with the fact that there have been vast advances in instructional technology, suggest that now is a good time to reevaluate current training methods, and devise a system which will enhance effectiveness in an absolute, not just a relative, sense. It is not necessarily logical to take the same course documentation, as is currently done, and exchange the terms "training device" for "actual equipment."

There is another difficulty which hinders the development of devices which are more training effective than the actual equipment. Although there have unquestionably been advances in the area of instructional technology over the past ten years, in the main there is no empirical evidence to support their effectiveness. Researchers have been pleading for more background investigation into these areas. However, although virtually every technical paper on the topic seems to end with a statement of this need, the research itself is being done slowly. If we truly wish to improve the quality of maintenance technicians -- and concomitantly the operational readiness of the Armed Services -- it is well past the time to earnestly investigate these matters. More comprehensive performance data must be collected, and a longitudinal data base developed so that meaningful judgments of effectiveness can be made.

Some of the reasons for the lack of empirical evidence supporting the worth of training devices vis a vis effectiveness have been discussed in this paper. However, the lack of such evidence is not surprising: course approach does not change with the addition of a trainer; better instructional technology is not implemented in trainer design; the usefulness of the various instructional technologies is not known and is not being researched. Training devices currently represent an engineering solution to a nonengineering problem. This must be changed. Creative designs and solutions in training terms must be applied in the development of such devices, with the application of new techniques to this new technology.

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TRAINING EFFECTIVENESS EVALUATION OF DEVICE A/F37A-T59

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ABSTRACT

The 34th Tactical Airlift Training Group (TATG) at Little Rock AFB provides initial and tactical mission qualification training to C-130 crewmembers. One of the new features of the newly delivered simulators is the inclusion of Stationkeeping Equipment (SKE). A complex set of procedures for proper utilization of SKE during formation airdrops forms a large portion of the tactical mission qualification training course. The Training Programs Branch of the 34th TATG conducted a study to explore the application of the IFS to pilot and navigator training. The study was conducted using four test classes. After a standard academic course, classes of pilots and navigators were divided into test and control groups. The test groups were trained using a pre-designed simulator syllabus and their performance was measured in the aircraft. The control groups received their training only in the aircraft before completing the same performance measurement. The study results in terms of subjective and objective data showed that the IFS could reasonably support a training effectiveness ratio of approximately 0.5. The best training strategy appears to be an integration of IFS missions among flying missions and ground training rather than in one block. We recommend inclusion of the IFS in mission qualification training. We also recommend a re-evaluation of the mechanics of the proficiency advancement concept.

INTRODUCTION

Background: The 34th Tactical Airlift Training Group at Little Rock AFB is tasked to provide the DOD C-130 training to student pilots and navigators. Mission qualification training covers the areas of airdrop, formation, and shortfield operations. Student pilots and navigators learn formation procedures for both instrument and visual operations. Formations in instrument conditions rely on Stationkeeping Equipment (SKE) to maintain aircraft separation. Training SKE procedures makes up a large proportion of the curriculum.

Stationkeeping Equipment: The Intraformation Positioning Set AN/APN 169A is a system which allows up to 36 aircraft to maintain fixed separation between airplanes in formation, and to locate and identify each other during day and night flights under instrument conditions. Operation of this equipment and specialized procedures for formation flight involving pilots and navigators are the main areas of concern in this study.

Instrument Flight Simulator (IFS): In November 1980, the first C-130E flight simulator, type A/F37-A159, was shipped from the Singer-Link Corporation, Binghamton, NY to Little Rock AFB. This technologically advanced aircrew training device (ATD) provides a training environment using a simulated C-130 aircraft cockpit. The cockpit can provide simultaneous training for a pilot, a copilot, a flight engineer and a navigator, controlled from an onboard, console-type, operators' station. The IFS is equipped with a six degree of freedom motion base which can provide highly realistic motion cues. A list of some of the simulator's other design capabilities includes full SKE airdrop simulation, radar simulation, manual or pre-programmed malfunctions, a library of demonstrations of typical maneuvers such as instrument approaches or airdrop procedures, and an emergency procedures monitor function.

Acceptance test procedures on the IFS were completed at Little Rock AFB in April 1981. The USAF Airlift Center Interim Report presents conclusions concerning IFS capabilities based on Qualification Operational Test and Evaluation (QOT&E) results (1). Some of the conclusions were: 1. The new simulator is superior to its 20 year old predecessor. 2. The new simulator is capable of training crew tasks that cannot be accomplished in the old simulator. 3. The navigator station enhances navigator training and crew coordination. Annex C of that QOT&E lists special aircrew tasks that were found to be trainable, partially trainable, or not trainable in the IFS. Among those tasks listed as trainable were: Stationkeeping Equipment checklist SKE formation escape, SKE formation recovery, airdrop checklist, and airborne radar approaches. This information suggested that the new simulator would have direct application to pilot and navigator mission qualification training.

Summary of Primary Objectives: In June 1931, the Training Programs Branch of 34th TATG initiated a study to explore possible application of the IFS in pilot and navigator mission qualification training. Listed below are the four areas of principal concern in this study arranged in order of decreasing importance.

1. The primary objective of this study was to examine the transfer of training using this device. Positive transfer implies that as a result of training in the simulator, less time is needed in the aircraft in order to attain a predetermined performance criterion.(2, 3) 2. A second objective was to investigate possible course structures to optimize simulator effectiveness. Also under consideration was the best arrangement of the course from the point of view of efficient scheduling. 3. The third objective was to produce and prove simulator courseware and job performance aids. Since SKE procedures had never before been presented in a simulator there was no applicable courseware in existence. 4. An additional objective of the study was to determine the efficacy of the instructor training program. A further task was to establish a qualified force of instructor pilots and navigators in adequate numbers for the study.

METHOD

A number of types of training effectiveness studies were considered. The transfer of training design was determined to be the most appropriate to determine whether ATD training would improve a student's subsequent performance in the aircraft (4).

Study Design: Through the use of a transfer of training design, experimental and control groups would be evaluated both objectively and subjectively. The methodology of data gathering required that experimental groups be exposed to a pre-designed simulator syllabus and then have their performance measured in the aircraft. The control group would receive their training only in the aircraft before completing the performance measurement. There were many constraints placed upon the implementation of this experimental program.

Time and Numbers: One of the most profound limitations was the availability of simulator time. In July, utilization reached 48 hours divided into four, 12 hour days. All use of the simulator was lost after 1 Oct 81 due to installation of a visual display system. Based on this limited simulator availability four student crews each from classes 81-012, 81-014, 81-016, and 81-018 were selected as the test group. The remaining students in these classes and the student population in the intervening odd numbered classes made up the control group. The student test group was composed of 30 pilots and 15 navigators. While it would have been desirable to get a more statistically significant sample for the test group, the actual number of subjects was thus limited.

Missions: Numerous studies have shown that a training effectiveness ratio of .48 is a good average value (5). This value was used as a starting point from which planning proceeded. Based on simulator time available, frequency of class starts, and the number of days allocated for flying training, a preliminary decision was made to produce a training block of four simulator missions. Existing instructional plans were changed only in the flying phase of instruction for both pilots and navigators. For the test group, this change included four simulator missions and six flying missions followed by the standard evaluation. The planned sequence after academics became one flying mission, a block of four simulator missions, five more flying missions and an evaluation.

The simulator was designed to allow for preprogramming of mission profiles. Due to system limitations during IFS testing, this feature was not available for this study.

Subjects: The first class was conducted with students handpicked on the basis of previous C-130 experience or strong performance in the initial qualification course. With this background, they would not be hurt by any shortcomings in the initial syllabus (6, 7). Also, the best qualified students were expected to point out weak areas in the program. Students from the next three classes were chosen so that the test group would closely approximate the control group in experience and aptitude.

Data: The data collected for this study fell into one of two categories, subjective or objective.

Subjective Data: The instructor mission reports provided course developers with their first feedback for improving the course as training progressed. This report aided developers in resolving student critique items.

Students were asked to complete a critique of the simulator course before and after the flying phase of training. The critiques used a 1 to 5 numerical grading scale to rate approximately 18 course-related areas with room for comments and student data. In this way, student attitudes could be gauged before flight training to get immediate feedback on the details of the simulator curriculum. The critique administered after the flying phase was intended to indicate the student perceptions of simulator realism and how well it prepared them for their aircraft missions from the perspective of course completion.

In order to get the instructors' overall view of the course, a meeting was held on 30 Oct 81 after all simulator training was completed. The instructors had had enough time to mull over the program by the time the comments in the mission reports were raised for general discussion. A consensus was reached in each case about the validity and relative importance of each item reported. This also provided a trigger for further discussion on several topics. This meeting was the last source of subjective data considered.

Objective Data: Numerical data is extracted from student training records and evaluation worksheets. Instructors assign performance and knowledge grades based on student proficiency. The grading system spans the numerical grades 1 to 4 for performance and A to D for knowledge levels. Data on flying time and number of sorties completed can also be obtained from these forms.

Courseware: Instructor guides and student study guides are routinely distributed as a part of courseware for the academic and flying phases of training. With the addition of simulator missions, additional guides were developed for both the instructors and the students. These test guides were developed with two objectives in mind: the need to prepare students to use the simulator time effectively, and the need to adequately prepare instructors for the unique simulator training mission.

PROCEDURES

The test program will be considered in terms of two major phases: Design and Implementation. Also considered here will be the problems encountered throughout the study.

Design Phase: Course developers were first exposed to the IFS in Aug 80 on a Training Group sponsored trip to the Singer-Link plant at Binghamton, NY. During the visit, Singer-Link personnel demonstrated the capabilities and design charateristics of the cockpit simulator, the instructor onboard station, and the motion base. The developers returned after four days with enough data to prepare a preliminary planning document in Oct 80 that outlined assumptions, a scenario for incorporating the simulator in training, a study proposal and possible mission profiles.

After the simulator arrived, it became apparent that the test profiles in the computers were unsuitable for training. It also became apparent that neither the equipment nor qualified personnel were available to reprogram the memory discs in the computer. This fact had a major effect on courseware planning and the instructor qualification program since the developers had hoped to train the instructors on the mission profiles to be later used with students.

Implementation Phase: The first mission qualification students (class 81-012) began simulator training on 23 Jun 81. The last student crews completed simulator training on 1 Oct 81 and completed the course on 26 Oct 81.

Between each of the classes, course developers made revisions to students materials as required. Course developers consolidated, printed, and distributed additional techniques covering simulator operation and failure trends. Training time was saved as the instructors were made aware of the experiences that preceding instructors documented on the mission reports. In general all possible aids were provided and improved throughout the program to insure peak efficiency of student training and maximum instructor acceptance of the program.

All students considered in this study attended the standard academic training program. For pilots, this meant five days of academics followed by an initial flying mission and then a final academic day. For the navigators, there were eight days in academics and then the first flight mission. Following academics, the students who made up the control group flew a scheduled program of eight missions and a flight evaluation. The actual number of missions an individual completed varied.

Upon completion of academics, the simulator group began a block of four simulator missions of four hours each. The actual number of days needed to complete this training varied due to simulator availability. There was some flexibility built into the profiles to allow the instructors to concentrate training on individual student weaknesses.

At the end of the simulator phase, the simulator students flew a program of six flying missions and a checkride. The test program called for these training flights to concentrate on low level visual procedures. To accomplish this, the test group and the control group would fly in separate formations during the flying phase. After the test group's fourth flying mission, the two groups could be integrated into the same formation in order that the test group fly in SKE formations as a review prior to their checkrides. This plan proved largely unworkable for operational reasons, so the flight mission profiles flown were essentially the same for both groups.

Problems Encountered: Other than the resistance to change anticipated in a significant alteration of training, the following major problem areas were encountered during the test program: simulator maintenance, instructor attrition, and scheduling as it affected profile changes and proficiency advancement. These problems existed during the entire test program, and although they were overcome to the extent that the program was completed, they will continue to impact any full-scale incorporation of the simulator into mission qualification training. The background and impact of the problem areas will be considered here; possible solutions can be found in the Recommendations section.

Simulator Maintenance: The most obvious problem that arises when trying to create a new training syllabus, simultaneously with full-scale development of an ATD, is building a core of knowledge about the device. In the case of IFS maintenance, this was particularly true. The manning level had been fixed at a number of personnel to maintain the four old analog simulators plus two new devices. During the study period, this manning was required to maintain the four old simulators, the new IFS, and two Cockpit Procedures Trainers. Additionally there was a requirement to retrain maintenance personnel from analog to digital logic.

One area of maintenance particularly affected by manning and training was simulator software. During the study period there were literally hundreds of software deficiencies the status of which was still unresolved between Singer-Link, Aeronautical Systems Division (ASD), and the Data Base Engineering Prototype Site (DEPS) personnel. Due to the manning limitations and training level of those assigned to DEPS, very few discrepancies were corrected during the study period. Instructors were forced to ignore and train around the vast majority of software errors.

Instructor Attrition: In order that the test program have a fair chance for success, qualified and motivated instructors were required. In the inital stages of the program, experienced and motivated instructors were hand picked to attend the Simulator Instructor Course (SIC). The intention was to use the same instructors during the entire period to eliminate the variable of differing instructor abilities from the transfer of training study. There was no problem retaining qualified instructor navigators in the test program, but this was not true of instructor pilots.

The instructor continuity policy, two week class start interval, tight summer manning and instructor pilot losses combined to severely limit the number of available simulator qualified instructors. Although the test plan recommended the use of the same instructors as much as possible to eliminate variability of instruction, this was not feasible for the pilots. Considerable extra effort was required to train replacements within the minimal amount of remaining time available on the device. In contrast to the pilot situation, the instructor navigator force remained relatively stable.

Scheduling and Profile Changes: Another variable that course developers endeavored to hold constant was the content of the flying mission profiles. From the third mission through evaluation, the profile contains a SKE formation route, airdrop and approach followed by two visual formation low level routes, airdrops and visual recoveries. The test program differed from the existing profiles beginning at mission three. Missions three and four were proposed to be visual formation missions to balance the heavy SKE emphasis of four simulator missions. The remaining missions and the evaluation were to concentrate on SKE/visual profiles with the intent being alanced mission emphasis prior to the evaluation and course completion.

The profiles actually flown during the test program did not adhere closely to the guidelines for either the normal or the test program profiles. During the test classes, it was impossible to fly the test group independently of the control group. Only infrequently did all the test group aircrews make up a formation for which only visual formation events were planned. Discussion of the effects of the heavy emphasis on SKE by the test group will be considered under the Conclusions section.

The end result was that although course developers had hoped to test a specific sequence of simulator and flying missions, scheduling produced a hybrid sequence of missions based on what existed and what was desired. The all-visual missions of the test group were never realized. Seven rather than six missions were actually flown, as a rule.

Scheduling and Proficiency Advancement: The courses administered by this training group operate under the concept of "proficiency advancement". Proficiency advancement is an operating theory under which each student must demonstrate proficiency at a task before he or she can advance to the next phase of training or be recommended for evaluation. The lack of true proficiency advancement was found to be based on a limited flexibility in the scheduling of flying time, constraints arising from simultaneous training in multiple crew positions, an informal instructor rating system, and the constraints associated with accomplishing training events. These factors tend to discourage proficiency advancement and cause the vast majority of students to fly about the same amount of time each class. This problem is further discussed in Conclusions.

RESULTS

The results of the test program will be presented in two parts. The first part will deal with the students and the second part will consider the instructors. While there is some overlap in these two areas, for the most part, they are distinct topics.

Students: The test program encompassed 30 student pilots and 15 student navigators. The data compiled on these test subjects and the control group will be presented here.

The pilot students were well qualified with an average of 2118 flying hours (1631 hrs C-130). The copilots were mostly recent UPT graduates with an average of 438 total hours (42 hrs C-130). The navigators had a mix of experience levels ranging from 7000 hours to 140 hours with a total flying average of 1924 hours (650 hrs C-130).

Students completed critiques which rated individual areas of course design and effectiveness. A five point scale was employed with catagories labeled from "poor" to "outstanding". Critiques were completed at the end of both the simulator and flying phases. The ratings were consistently excellent to outstanding in most areas. Of particular interest were the overall ratings (pilot and navigator responses combined) at the end of the flying phase. Seventy-six percent of the students rated the simulator excellent or outstanding as a transition to the aircraft. Sixty-nine percent of the students similarly rated the program outstanding as a transition to the flying phase.

In addition to the ratings, the students made comments on the critique forms. Some of the comments dealt with suggested changes in the missions, such as more or fewer malfunctions. These suggestions were acted upon when feasible. The size of the list was deceptively long. Some of the comments were contradictory and thus their validity is suspect. For instance, some students in class 81-016 recommended elimination of SKE lead time while others recommended an increase. The remainder of the unresolved comments will be studied further to improve the syllabus. The largest comment area was praise for the course as beneficial.

Averages for the number of sorties and flying time expended for training classes during the summer of 1981 were tabulated. The results show that the test groups experienced fewer average sorties and flying time than the control groups, but not by the margin hypothesized in the Method section. This information is summarized under Program Averages (figure 1). It should be noted for class 81-014 and 81-016 that, although the students completed training with fewer flying hours and number of sorties, the test group required more training days than the control group. The cause of this anomaly can be traced to the profile changes, and the effect of the increased number of training events generated by the use of the ATD (discussed under Conclusions).

A complete listing of all the control group flight evaluation discrepancies was compiled for pilots and navigators respectively. A comparison was made of discrepancy areas and frequencies between test and control groups of pilots and navigators. This data shows significantly fewer discrepancies in the test group for SKE enroute formation position for pilots. SKE departure and SKE recovery discrepancy rates are approximately the same for control and test groups in relation to respective populations. No trend can be seen in navigator discrepancies when comparing test and control groups except in the area of SKE knowledge and use. Overall, SKE knowledge and formation position flying discrepancies appear to be reduced by the inclusion of IFS missions in the syllabus.

Also in figure 1, the overall percentages show that test group pilot and navigator students completed training without discrepancies more often than those in the control group. The test group accomplished this with fewer flying sorties and hours. There seems to be an insignificant difference in the number of days in training between test and control groups for the pilots. The navigators, in contrast, show a difference of about four days. The significance of all these areas with reference to the utility of the ATD with be further discussed in Conclusions.

Instructors: Based on the Instructor Mission Report ratings there seems to be no identifiable trend to the usage pattern of the simulator. Reliability rates for the device will be discussed later in this section. The instructor pilots and navigators indicated their perceptions of device operation and training value with a numerical rating. The data generally reflects a "good" rating for device operation and a "good" to "excellent" rating for training accomplished. There is a high correlation between the device operation rating and the training accomplished rating.

In addition to the ratings, the instructor comments were compiled from the instructor mission reports. Also tabulated were the frequency of the comment, area of responsibility and the status. Numbers of comments declined over the course of the test as the program was "debugged". A listing of maintenance related comments extracted from all of the instructor mission reports was correlated with frequency of occurrence and numbers of ineffective sorties. The data shows that of the 60 simulator periods required to support 15 student crews (3 classes x 4 crews x 4 missions + 1 class x 4 crews x 3 missions), 10 periods were lost and had to be rescheduled for an overall ineffective rate of 17%. There seems to be a decline in the number of maintenance related comments over the course of the program, but the number of ineffective sorties seems constant. The predominant maintenance problem varied from class to class. For instance, hydraulic control loading was a problem during class 81-014 while motion platform jerking and software problems affected classes 81-016 and 81-018 respectively. The problems listed are fairly evenly distributed between hardware and software. Additional training time was lost or the content degraded by less significant equipment malfunctions that went unrecorded.

As with the unresolved student comments, some instructor comments on the same topic are contradictory and their validity is questionable. To resolve these contradictions and other comments, an after action meeting was held on 30 Oct 81 with all available instructors. The remainder of the comments will also be studied further to improve the syllabus and operations/maintenance interaction.

PROGRAM AVERAGES

Statistical Area	PILOTS Test Group	PILOTS Control Group	NAVIGATORS Test Group	NAVIGATORS Control Group
Ranks				
2LT	9	45	8	13
1LT	1	7	0	2
CAPT	15	37	1	4
MAJ	4	16	4	1
LTC	1	5	2	0
TOTAL NO. OF SUBJECTS	30	110	15	20
SORTIES PRIOR TO RECOMMENDATION	7.2	8.8	7.6	8.4
HOURS PRIOR TO RECOMMENDATION	32.1	38.0	N/A*	N/A*
# OF DAYS TO COMPLETE FLY PHASE	20.7	20.3	22.6	18.3
CHECKRIDE RESULTS				
Q-1	26 - 87%	79 - 72%	11 - 73%	14 - 70%
Q-1/2	1 - 03%	21 - 19%	0 - 00%	3 - 15%
Q-2	3 - 10%	6 - 05%	1 - 06%	1 - 05%
Q-3	0 - 00%	4 - 04%	3 - 20%	2 - 10%

* Data not available. Not considered relevant due to use of only pilot data for flying program scheduling.

Figure 1

CONCLUSIONS

Primary Findings

Transfer of Training: A transfer of training ratio of .48 was originally hypothesized. Based on a program of four simulator missions, this rate would suggest an approximate savings of two flight missions while holding training standards constant. The subjective and objective data collected by this study, with some qualification, support the hypothesis.

The overall flight evaluation results (see figure 1) clearly show that Q-1 rates were not degraded with the adoption of the ATD. The pilot data even suggests a slight improvement in this rate. In the specific subareas related to SKE procedures there was a significant improvement for both pilots and navigators. For pilots there was a 59% decrease in the number of SKE related discrepancies. For navigators there was a 100% decrease (the actual number of discrepancies declined from two to zero).
The number of aircraft missions flown prior to evaluation (sorties use rate) also declined with the addition of the ATD. The decrease was 1.6 and .8 sorties for the pilots and navigators respectively. Although this decrease does not fully support the hypothesised transfer of training rate, there is evidence that this rate was adversely affected by factors unrelated to training. This subject will be discussed under weaknesses of the Study in this section.

Student and instructor feedback, as derived from critiques and mission reports, strongly supported the use of the ATD for SKE training. On 30 Oct 81 an after action meeting was held with all available instructors who had participated in the SKE test. The consensus recommendation for future simulator use was a program of four simulator missions and six or seven flying missions plus a flight evaluation.

Course Structure: Data from this study suggests that a block of simulator missions is not the most effective or efficient structure for use of the ATD.

The addition of simulator missions to the training program increases the total number of training events in the flying training phase from fourteen to sixteen. This increase in the number of events caused an increase in the number of days required by the test group to complete the course (see figure 1). In the interests of safety, instructors are usually restricted to a maximum of three actual flying missions per week. By integrating simulator missions in the flying phase the greatest number of training events can be accomplished in the time allotted.

The integrated structure may also be the most effective use of the ATD from a transfer of training point of view. Instructors noted a weakness in the blocked schedule used for the test. The test plan called for a sequence of two visual flight missions, four SKE simulator missions, then the remaining flying missions.

Instructors pointed out that students were inclined to forget visual procedures during the concentration on SKE in the simulator. Instructors felt an integrated approach would make better use of all missions. This was the recommendation of the instructors attending the after action meeting.

Courseware: Courseware included a variety of guides and job aids designed to assist the students and instructors in the use of the ATD. One of the objectives of this study was to prove these support materials. To some degree this effort was hampered because much of the courseware was revised in response to student and instructor comment during the test. Thus, the courseware as an independent test variable was not held constant. However, based on positive feedback from instructors and students, plus the positive transfer of training rate for the program, the test basically proved the efficiency and validity of the materials. Further testing for validation is suggested under Recommendations.

Instructor Training: Sufficient simulator instructors were qualified to complete the study. There was no specific data collected on the relative competence of these instructors but it may be assumed from the positive overall study results that minimum competence was attained. There were two programs used for instructor qualification. The first was a highly structured program including an academic block and a hands-on training block. The instructor's after action meeting recommended specific improvements to this program. They are: 1. Reduce the length of the academic phase, 2. Increase the amount of hands-on training, and 3. During hands-on training, include training missions with actual students. A less formal check out program was used to make up for instructor attrition during the test. This program involved "piggy backing" instructor candidates on training missions with fully qualified instructors. Although this program is less desirable than the first, it did meet the need for qualified instructors.

Additional Findings

Maintenance Support: ATD maintenance had a major impact on the test program. The test was hampered by hardware and software deficiencies throughout its run. Some deficiencies were the result of incorrect initial design while others were due to maintenance manning and skill levels.

Some deficiencies remain uncorrected due to the low maintenance manning and training levels which currently exist. Manning levels for the IFS will improve as the old simulators are decommissioned. It is to be hoped that knowledge levels in the maintenance ranks will increase with the conversion of personnel from analog to digital systems and with more experience maintaining this device.

Training Capabilities: Some important training capabilities were not designed into the ATD. For instance, one important training task is the performance of SKE procedure turn recoveries in the wing position. A capability of the simulator to train this task was never contracted for and thus never designed. As another example, trainers desired to use the concept of "backward chaining". This concept refers to a way of training a task which is made up of a series of chained subtasks. The final subtask is practiced first, then the last two subtasks, then the last three, and so on until the entire task is practiced. This concept works particularly well when the last subtask is the most difficult, since the last subtask is the most practiced. In airdrop training, the final subtasks are the most difficult to master and thus this technique could have proved very useful. However, the design of the SKE computer program required the triggers of a departure, climb, descent and slowdown in order to make an airdrop. Multiple approaches to the drop zone cannot be accomplished without flying an entire route. At some future date this basic programming may be rewritten, but these training events cannot be accomplished at this time.

In addition to deficiencies in the design and initial programming of the device, some other features of the device were unuseable. The automatic profiles, performance measurement, prerecorded demonstrations and auto message features all had a questionable reliability record. Their intermittent operation caused a degree of frustration in the instructor ranks. A large number of software changes will be required before these features are useable.

The user/trainer should not expect perfect performance from a prototype ATD during the installation and testing phase. Eventually, logistic and maintenance support should meet expectations. Long procurement lead times are to be expected on software and hardware items for a new device. The procurement contract clauses that specified testing in the plant and at the site and a data freeze date of 1977 may have provided some protection from defect in the ATD, but they also extended the time at which maintenance and logistic support will catch up with desired training quality.

Weaknesses of the Study: In the method section, the course developers proposed to extract results from the grade sheets to support collection of objective data. This was not done because of the limited value of this data. Whenever an evaluator remembered to complete the evaluation column of this form, all areas applicable to SKE formation position and procedures were usually graded at the minimum level of proficiency. The few evaluators who avoided this central tendency and showed some variation in performance and knowledge levels do not represent a numerically significant group for study.

This study has limited value because of the manner in which the objective data was collected. In the pilot mission qualification course, there are no specified criteria for the required level of proficiency in flying the SKE wing position. This position is flown 4,000 feet in trail for the number 2 wingman and 8,000 feet in trail for number 3. A criteria such as "maintain 4,000 feet in trail as number 2 wingman + 1,000 feet" does not exist. There are no specified limits in MACR 60-1, Aircrew Standardization Evaluation Program, in relation to acceptable limits of formation position. The SKE subareas on the evaluator work sheet are graded satisfactory or unsatisfactory. For this study, course developers have been forced to rely on subjective evaluator judgements of formation position and use the checkride pass/fail rates as objective data.

The control of variables was a major weakness of this study. Too many conditions in the training program were allowed to change over the course of the test. Training profiles, numbers of sorties, instructor personnel and other proposed parameters discussed under Problems and Results varied significantly. The test program missions in the new simulator were developed to complement the existing flying program. If the simulator had been an established training device, a change in training policy would have required validation of a modified flying program. Neither of these approaches is optimal. A training syllabus that teaches required tasks should be prepared and then training time apportioned to the ATD's or flying training based on the most effective and efficient utilization of these resources. Exercise of control over all phases of the training program design would have insured more accurate test results.

Two additional weak areas deserve discussion: proficiency advancement and the small number of test subjects. As discussed under Procedures, advancement was adversely affected by current scheduling practices. As discussed in this section, proficiency is rather ill-defined and event oriented. When the student has flown all the required events listed on the grade sheet on the required number of flying missions established by the Course Summary Document, he is generally considered proficient. In examining the term "proficiency advancement", as it was applied to the test program, it is evident that "proficiency" was a subjective evaluation with little basis in objective fact and that "advancement" was inflexibly based on their student's flying schedule. Neither of these problems could be overcome in the test program methodology by the relatively small number of test subjects. See Recommendations for applicability to future syllabi and any further investigations.

Instructor Utilization: A final point to ensure continued training effectiveness of this ATD is the single instructor concept. Even though this variable has not been adequately studied, there appears to be an increase in effectiveness when a single instructor is responsible for both simulator and flying training. This allows instruction given in the simulator to be more compatible with that given in the aircraft. This should reduce any possible negative transfer that could occur as a result of instructor idiosyncrasies (8).

Recommendations

Primary Recommendations: Until a significant amount of further data can be compiled from students in a mission training curriculum incorporating the IFS, the following recommendations are made regarding that curriculum:

(1) The IFS provides good initial Stationkeeping Equipment training and should be integrated throughout the flying phase of instruction.

(2) The course of instruction for pilots and navigators following academics should consist of four simulator missions interspersed with six flight missions and an evaluation.

(3) The simulator instructor candidates should receive one day of academic training, two simulator missions without students, three training missions with students and an evaluation (if required). Instructor training should be accomplished using the training syllabus for the instructor's course (9).

(4) The courseware that was developed for this test program should be formalized and used until validation on a statistically significant student population is completed.

(5) Greater emphasis on true proficiency advancement should be supported by managers and supervisors. Training should be less event oriented and scheduling handled with more flexibility.

Additional Recommendations: The following recommendations are of less immediate importance, but should also be implemented:

(1) Specific performance criteria should be established for tasks trained in simulator and flying training for the purpose of testing and validation. These criteria will promote standardized evaluation of student performance by instructors and evaluators.

(2) Continuing studies should investigate the rate of proficiency attainment in simulator and flying training to identify the best media for instruction.

(3) Adequate ATD time should be allocated for course development efforts.

(4) Continuing efforts should be made to improve ATD maintenance support and ATD reliability.

(5) A concerted effort should be made to improve IFS software so that all design capabilities of the device are fully useable.

Refining these features will ease instructor workloads.

(6) Every effort should be made to increase supervisory awareness and support for test programs and validation studies.

(7) Standardization and Evaluation should recognize the effectiveness of this device for student training as described in this report or conduct their own validity assessment.

It is through periodic management reviews and studies of this type that training policies are examined and constructive changes made to improve training techniques.

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THE INSTRUCTOR/OPERATOR STATION: DESIGN FOR THE USER

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ABSTRACT

The Instructor/Operator Station (IOS) of a simulator is the focus of user control of training exercises. Design of the IOS is, therefore, crucial if the user is to carry out his training roles and responsibilities efficiently. Unfortunately, IOS designs have often been poorly human engineered and have been based on insufficient training and human factors data. This paper (1) assesses IOS designs for current-generation Operational Flight Trainers (OFT) and Weapon Systems Trainers (WST), (2) identifies strengths and weaknesses, (3) develops an approach to improved IOS design, and (4) develops alternative IOS configurations. The alternatives are comparable in training capability. They differ in their primary methods of control: fixed-function console-mounted electronic touch pads versus variable-function CRT touch panels. The primary conclusion of the paper focuses on the importance of systematic application of training data with the resultant potential for improvement in IOS design and operations.

INTRODUCTION

In the past decade the states-of-the-art in both training systems and simulator technology have advanced rapidly. Innovation in training systems has resulted from the use of the procedures and techniques inherent in Instructional Systems Development (ISD). Simulator hardware and software advances have been numerous and varied (e.g., computer and software capabilities, visual system technology, data entry methods and data manipulation techniques). These innovations and a variety of other factors (e.g., fuel costs, safety, etc.) have led to escalation of the use of training devices. Indications are that this trend will continue in the foreseeable future.

In many instances it appears that technology has been the driving force in training device design. Devices have been designed because the technology existed, not because an analysis based on training requirements determined the best candidate and its capabilities to meet the training requirement. The results have been that money has been spent for technology with little regard to training effectiveness.

The Instructor/Operator Station (IOS) has been the recipient of much of the explosion of simulation technology. As technology has permitted higher fidelity simulation of more and more trainee tasks, it has also enabled expanded capabilities to control the simulation environment. These capabilities have been incorporated into the IOS. All too often selection and implementation of the capabilities have been based on insufficient analyses and data. As a result IOSs and the associated software have been poorly designed.

Training devices have been delivered with IOSs which are complex and difficult to operate. This has led to user frustration in not being able to use the device to its training potential. For example, many IOSs have multiple data entry methods such as switches, light pens, numeric keyboards, alphanumeric keyboards; multi-function switches; pages and pages of CRT information which must be called up before the specific item can be located, etc. Extensive formal training is required for the instructor/operator to become proficient. Daily use is required to remain familiar with the operation of the IOS. In the "real world" situation the instructor/operator may or may not have had formal training. More likely he has received an abbreviated on-the-job training program and does not use the device daily. Many instructors are, therefore, not qualified to administer training in the device. The result is that training quality, quantity, standardization, and efficiency suffer.

IOS design is not just the physical layout of a work place. It also encompasses consideration of instructional features, information management, software capabilities, and many other varied factors. To properly incorporate the many factors into an efficient training-effective design requires a systematic analysis process. It is apparent that many IOSs currently in use have not evolved through such an analysis and design process.

PURPOSE

The purpose of this paper is to present the results of a systematic analysis of past and current IOS designs, assess their strengths and weaknesses, develop design principles to enhance the strengths and to eliminate the weaknesses, and implement the principles in alternative generic IOS designs. The orientation of the paper is toward the identification of problems and the presentation of proposed solutions. The proposed solutions, if implemented, will provide an IOS which is readily usable and more training effective. In addition, reliability and maintainability will be improved.

Emphasis is on the IOS of operational flight trainers (OFT) and weapon system trainers (WST) for fighter/attack aircraft. Procedures, results, and recommendations, however, are also relevant to many other simulator applications.

IOS WEAKNESSES

There are significant differences in the design features of existing simulator IOSs. Some work better than others; some have sophisticated features, but do not work very well; others are simple and work quite well. Collectively, however, there are weaknesses which characterize OFT and WST IOSs. These weaknesses are as follows:

- Layout, labelling, coding, etc., do not optimize device operation and minimize instructor workload.
- Steps required to access many CRT displays are time-consuming and inefficient.
- Delays in display access cause inefficiencies in training problem control and monitoring.
- Data entry methods are confusing, redundant, and inefficient.
- Device complexities make it difficult for instructors to implement changes or modify missions to meet student needs.
- Many features and capabilities are not needed, not used, or difficult to use.
- Simulator capabilities are not keyed to the training requirements (i.e., objectives) of the training system in which it will be used. The simulators are, therefore, not properly integrated into the training system as an efficient element which fills a clearly-defined need.

There are other weaknesses which do not involve IOS design features, but which significantly affect IOS operation and use. These weaknesses are as follows:

- Instructor training does not adequately prepare instructors for their roles and responsibilities in using simulators.
- Instructor roles and responsibilities are not completely defined and implemented.
- Student training syllabi are poorly developed and used. Standardization, organization, efficiency, and quality of instruction are, therefore, impaired.
- Instructor handbooks are not properly organized and formatted to provide instructor assistance in operating the device in a training situation. They are massive informational volumes, not training tools.

When taken together the clear impression is conveyed that the total concept of design for the instructor is very "loose" (i.e., the systematic principles of man-machine interface, human factors, and training technology have not been properly applied). The net result is that planning and design for operation of the device are secondary components of the total simulator development process. Actual operation of the device and training using the device, therefore, suffer.

DESIGN PRINCIPLES

Clear delineation of IOS weaknesses provides the basis for development of problem solutions. The first step in developing specific solutions is to formulate a set of design principles from the IOS weaknesses. These principles translate the weaknesses into guidelines for improvements. The design principles in turn provide a framework for developing the design concept. Design principles which were derived from the IOS weaknesses are as follows:

- Reduce the instructor/operator requirements for formal training by providing an instructor/operator instructional aid system at or near the IOS. This feature will not only provide training in the operation of the device but will actively assist the instructor pilot (IP) throughout the training exercise.
- Emphasize the use of automated training as the normal mode of training.
- Reduce the instructor/operator workload by automating the ancillary tasks.
- Reduce the number and types of data entry methods at the IOS.

- Use "touch panels" on CRTs and electronic "touch pads" on the IOS console as the primary data entry methods.

- Design IOS layouts to enhance operation, interpretation, sequences of actions, etc.

- Eliminate the use of multi-function controls/switches.

- Standardize the nomenclature used on controls to reflect IP terminology.

- Investigate the use of color on CRT displays to highlight important points.

- Upgrade student and instructor training and operating materials.

- Improve reliability and maintainability by use of touch controls, and eliminate light pens, alphanumeric keyboards, etc.

- Reduce cost by limiting IOS capabilities to defined training requirements.

DESIGN CONCEPT

The design concept contains the essential elements to implement the design principles and to remedy the IOS weaknesses. It consists of two components: hardware and software. The components interact and are dependent one upon the other. A major issue in any design involving both hardware and software is establishing the proper functional balance between the two. In pointing out the distinction between hardware and software, there is an emphasis that IOS design is much more than using good human factors principles in determining what the IOS should look like. It is a systematic process of determining the information storage, retrieval, display, and manipulation requirements, and of implementing these requirements in a combination of hardware and software which optimizes instructor performance. Major design concepts are discussed in the following paragraphs.

Hardware

The IOS hardware must be reliable, maintainable and easy to operate, and yet must contain the components required for control, monitoring, and evaluation. Major hardware components of the proposed IOS design concept are as follows:

- The main console. The main console is compact, and is designed for a single instructor/operator. All layout is consistent with good human factors design principles. Particular emphasis is on ease of use of controls, orientation of CRTs for ease of display interpretation, and a functional work surface which accommodates instructor guides and checklists.

- Instructor Aid System (IAS) The IAS is a separate small CRT with associated controls. It is an integral part of the IOS and serves two functions: (1) presents instruction on basic trainer operation and (2) prompts and guides instructors during the course of training exercises. It may also be used to display selected cockpit instruments (e.g., multi-function display, horizontal situation indicator, etc.).

- Instructor's control panel. The instructor's control panel is the major "hard-wired" part of the IOS dedicated to simulator control. It consists primarily of fixed-function electronic touch pads.

- Monitors. The major components for data manipulation and display, trainee evaluation, and situation displays are CRT displays. Numbers, sizes, and locations of CRT displays are dependent upon the specific application. A typical application, as presented later in this paper, consists of three displays: one to monitor the visual scene and two to display data.

Software

In order to combine simplicity of hardware with complexity of weapons systems and training problems, it is essential that software be designed to enhance instructor performance. The software must be simple to manipulate, present information in easily used formats, and facilitate problem control and monitoring. Major features of the proposed software design concept to meet these goals are as follows:

- Display continuity. A given display is always presented on the same CRT. There is no switching of displays between CRTs at the instructor's discretion. When a display is selected or is called up automatically by the software, it always appears in the same place.

- Standardized displays. Each type of display has a distinct, precisely prescribed format which is always used for that type of display. Formats are developed to enhance interpretation and use of the information presented. Display highlights are emphasized by spacing, graphics, bold alphanumerics, etc. It is also recommended that color be used to highlight portions of the displays.

- Automatic presentation of displays. Maximum use is made of software selection of displays, so that minimum instructor intervention is required. During pre-programmed modes all displays are software selected. During free flight the amount of instructor display selection is minimized through keying displays to trainee tasks.

- Minimize steps to change displays. As discussed above, display location is standard. There is, therefore, no concern with where a given display will appear. Also displays which are candidates to replace a given display being presented on a CRT are selectable using the touch pads on the CRT face. In most cases changing displays will require a one-touch step. In most other cases software design should minimize the number of decision points (i.e., steps) the instructor must handle.

- Minimum steps to manipulate training exercises. Minimum steps to manipulate is closely related to minimum steps to change displays. In this case, however, rather than changing displays for monitoring purposes only, the instructor is locating the display from which he will affect training problem control (e.g., locate and select a specific emergency, locate and activate a specific navigational beacon, etc.).

- Large selection of programmed exercises. One of the strengths of the proposed approach to IOS design and operation is a high-quality front-end analysis. Among other things, the analysis yields a realistic training device syllabus which is keyed to the training requirements and training situation. The programmed exercises designed from the syllabus are, therefore, essential parts of the total training system and should be administered to each student. The large selection allows consideration of student skills and progress, a variety of equally difficult exercises for different students, standardized training, programmed exercise capability for all training phases, and elimination of time-consuming set-up required in conventional free flight exercises.

- Large selection of initial conditions. On many simulators, setting up initial conditions in the free flight mode is time-consuming, and may be nonstandard. A large set of initial conditions gives instructors the flexibility they desire and improves use of time and standardization. In the proposed IOS, selection of a given set of initial conditions would key other responses from the IOS. For example, selecting initial conditions for an aircraft on the parking ramp may activate display of the normal cockpit checklist, or selecting initial conditions for an aircraft in the holding pattern may activate the carrier approach display.

- IAS teaching and prompting. The IAS has two primary roles. The first is to teach instructors how to use the simulator. In this role it is a CAI terminal used to present information on the operation of the IOS and on the procedures for conducting training exercises. The second role is to prompt instructors during set up and execution of training exercises. In this role the IAS is a job aid which improves instructor efficiency and standardization of instruction.

DETAILED DESIGN ALTERNATIVES

Two generic alternative IOS configurations are presented. Both use fixed function electronic touch controls on the IOS panels and fixed and variable function touch panels on the CRTs as the methods of simulator control. The primary difference between the two alternatives is the division between the methods of simulator control. In Alternative 1, the use of electronic touch controls is confined to basic simulator operation (e.g., power, motion system operation, freeze). Touch panels on the CRT faces are the primary method for controlling training exercises.

In Alternative 2 there is an increased use of fixed function electronic touch controls mounted on the IOS vertical panel. These controls are used to carry out many of the functions for which CRT touch panels are used in Alternative 1. CRT touch panels are also used in Alternative 2.

Alternative 1 is an extension of the state-of-the-art being used to design the current generation of simulators. Emphases are on a minimum use of hard-wired controls and a maximum use of software control through input sources which are displayed as required. Alternative 2 is an update of the basic approach used in earlier generation simulators (i.e., extensive use of hard-wired controls). State-of-the-art technology is used in both the control methods chosen for Alternative 2 (i.e., electronic touch pads and CRT touch panels) and problem control software.

These two alternatives are the two ends of a continuum, one extreme of which is CRT touch panels and the other extreme of which is console-mounted electronic touch pads. Although Alternative 2 does not involve complete control via electronic touch controls, it is considered to contain the most extensive feasible use of electronic touch pads in light of the current technological state-of-the-art. More extensive use of electronic touch pads in lieu of CRT touch panels would lead to an IOS design which violates many of the principles of compactness, ease of use, and information management.

Other candidate alternatives in addition to those presented would fall between the two extremes (i.e., would consist of different mixtures of console-mounted electronic touch pads and CRT touch panels). These alternatives would constitute a set of virtually unlimited permutations of combinations of electronic touch pads and CRT touch panels. Presentation of all such alternatives would be virtually impossible.

By providing the anchor points of the continuum (i.e., the two feasible extremes) rather than numerous alternatives, the concepts of operation of each basic IOS type can be clearly presented along with the advantages and disadvantages of each. Variations of an IOS type for a specific application can be identified based on specific simulator requirements and personal preferences of Subject Matter Experts (SMEs), analysts, and engineers.

Alternative 1

The first alternative features a high level of automation to assist instructors, and simulator control via CRT displays which contain touch panels on the face of the CRT. The basic configuration of the IOS is shown in Figure 1.

Hard-wired controls are confined to:

- Operation of displays (e.g., power, brightness, contrast).
- Basic trainer control (e.g., power, freeze, motion).
- Communications with the trainee and maintenance.
- Miscellaneous problem control (e.g., crash override, barrier arrest, catapult fire).
- Numeric keyboard.
- IAS control.

All other controls are programmed to use touch panels on the faces of the two CRTs. Specific touch panels for each display are programmed and are presented in the lower portion of the display.

The selection of touch panels by display is based on an analysis of the options which instructors may choose to exercise at a given point in a training exercise. The options are derived from the trainee and instructor tasks in progress and the associated displays used to monitor trainee performance. This philosophy enables instructors to select alternative displays, insert malfunctions, modify weather, etc., without having to carry out a multi-step selection process through a series of menus. Rather, selection alternatives have been built into the software and are readily available through the touch panels on the two CRTs. This feature will have a major positive effect on instructor workload and ease of IOS operation.

Although emphasis is on the use of preselected alternative actions during the course of a training exercise, the IOS has the capability to allow more flexibility of instructor action. Through the use of a series of menus which tie back to a master menu, instructors are able to have greater control over simulator operation. It is essential to emphasize, however, that through proper programming based on an accurate analysis, the normal method of operation will be through the programmed alternatives presented on the CRT touch panels. The more time-consuming, and potentially confusing processes of working through the selection menus is meant to be the exception rather than the rule.

Another feature which reduces instructor workload is extensive use of programmed exercises and a large set of initial conditions. The initial conditions are easily selectable. Through the software they affect the displays and alternatives for trainee tasks carried out in the initial condition environment.

It is recommended that the "normal" mode of operation be with programmed exercises. The exercises should be derived from a well-integrated, approved syllabus in which the simulator plays an integral role in the training sequence. The programmed exercises facilitate standardization of instruction, but retain the capability for on-line modification in response to trainee performance (e.g., insertion of additional malfunctions, changing environmental conditions).

A large set of exercises (i.e., 25 or more) should be programmed and updated as required to incorporate procedural changes, tactics changes, etc. This will give instructors the capability to vary the scenarios within a type and difficulty level, and also to have a wide range of types and difficulty levels available.

The free flight mode requires the greatest instructor involvement. Operations in the free flight mode, however, are designed to reduce instructor workload. This is accomplished through the IOS software. Routine decisions and selections are made by the IOS. In many cases instructor intervention is by exception. For example, given that the trainee is performing a certain task which has been selected by the instructor, displays to monitor trainee performance will be selected and presented by the software. Also, the most likely alternate selections and most likely subsequent trainee tasks will be available as CRT touch panels. Only if different alternatives are desired will instructor intervention be required.

A large set of programmed initial conditions (i.e., 40 or more) plays a major role in operation of the free flight mode. This set should be derived from a systematic analysis of (1) conditions under which a training exercise will begin and (2) conditions to which the simulator will be reset during the course of exercises. Through use of programmed initial conditions, initial set up and reset times will be minimized.

The intent is to use the initial conditions as programmed, without modification. If the set of initial conditions is based upon an accurate analysis, this should be the case. The software, however, contains the capability for on-line changes to selected parameters. It is recommended that weather and stores be changeable on-line. Changes to any other parameters would be made off-line. The ability to make changes, both to initial conditions and programmed exercises, should be tightly controlled. Such changes should result only from periodic training conferences

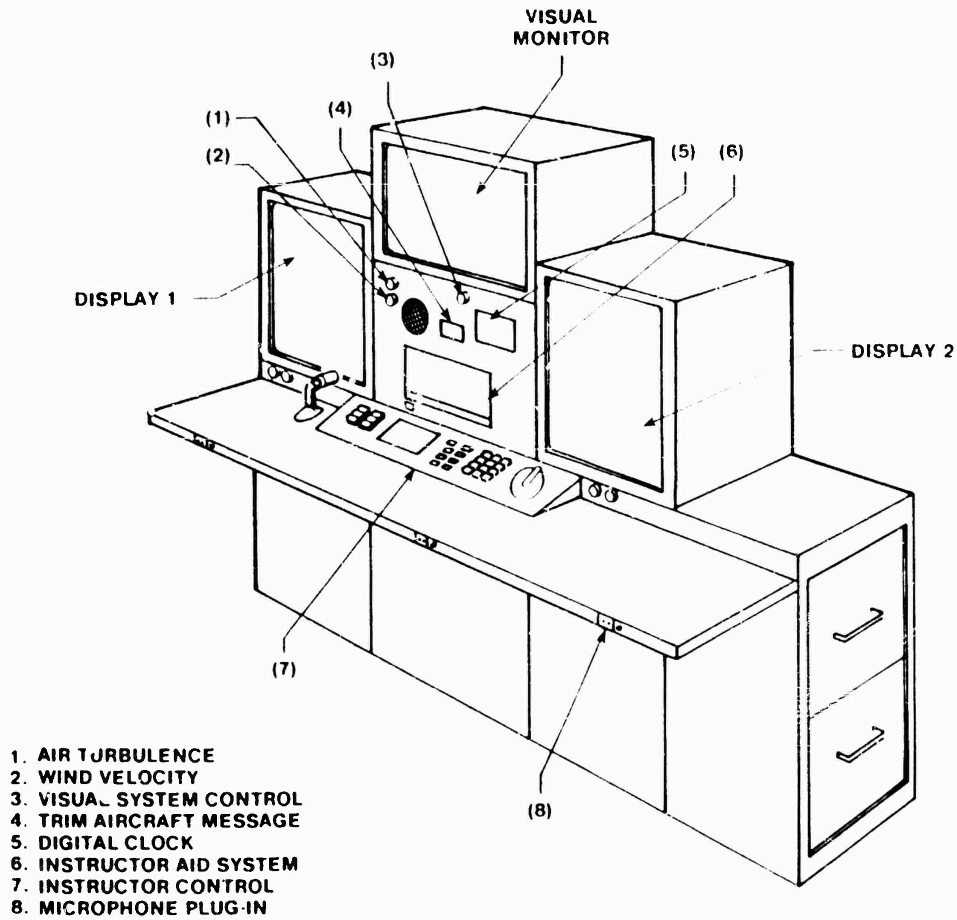

Figure 1. Generic Instructor/Operator Station - Alternative 1.

and reflect the consensus of the training community. Otherwise, the programmed events may be based upon the whims of the individuals who like to make changes.

Alternative 2

The second alternative also features a high level of automation to assist instructors. The major difference is that many of the instructor actions which employed CRT touch panels in Alternative 1, employ fixed-function electronic touch pads on the IOS console in Alternative 2. The basic configuration of the Alternative 2 IOS is shown in Figure 2. Hard-wire controls are used for the following functions. Note that the first six (marked with an asterisk) are the same as in Alternative 1. The remainder are additions to Alternative 1, and indicate the major hardware difference between the two alternatives.

- Operation of displays (e.g., power, brightness, contrast).*
- Basic trainer control (e.g., power, freeze, motion).*
- Communications with the trainee and maintenance.*
- Miscellaneous problem control (e.g., crash override, barrier arrest, catapult fire).*
- Numeric keyboard.*
- IAS control.*
- Mode control.
- Selection of automated training exercises, checkrides, and demonstrations.
- Selection of types of normal and emergency procedures.
- Selection of malfunctions by system.
- Selection of specific pre-determined malfunctions.
- Dynamic replay control.
- Print control.
- Selection of cockpit instrument monitor by cockpit section.
- Selection of map displays.

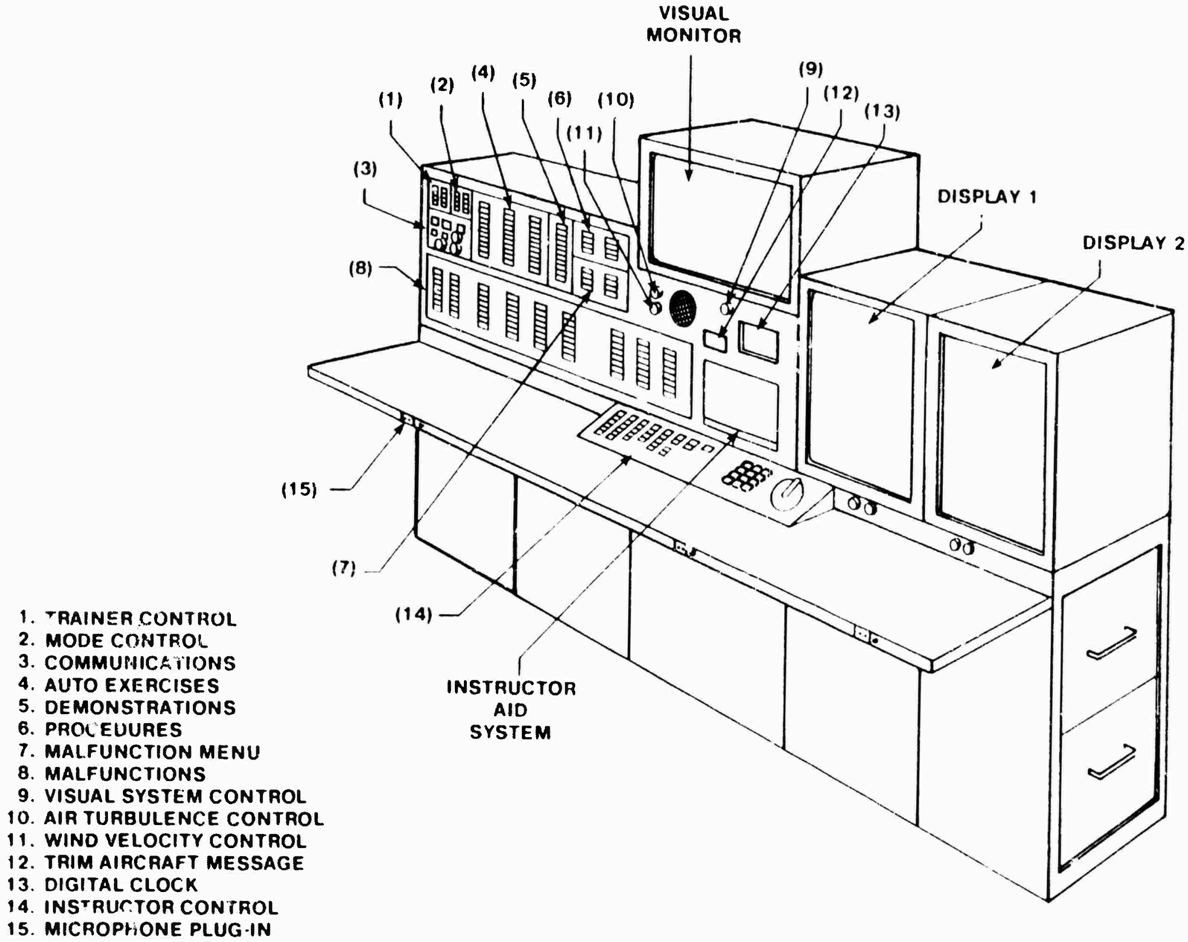

Figure 2. Generic Instructor/Operator Station - Alternative 2.

- Selection of environment/aircraft data displays.

Other controls are via the CRT touch panels, as used in Alternative 1. Typically the IOS console touch pads are used to access the initial display. Alternatives emanating from the initial display are typically controlled from touch panels on the faces of the CRTs.

The identification of CRT touch panels for each display is based on an analysis of the operations which instructors may choose to exercise at a given point in a training exercise. Determination of display content is based upon requirements to monitor trainee performance of specific training tasks and to control the training exercise. These philosophies are the same as those used in Alternative 1. They are designed to enable instructors to select alternative displays, insert malfunctions, modify weather, etc., without having to carry out a multi-step selection process through a series of menus.

There are a number of other fundamental philosophies/techniques in Alternative 2 which are consistent with those discussed previously for Alternative 1. These are as follows:

- A set of menus and selection options for problem control.
- Large sets of pre-programmed exercises and initial conditions.
- "Normal" mode of operation with programmed exercises (i.e., automated training exercises).
- Extensive instructor prompting and pre-selected options in the free flight mode.
- Only limited capability to make on-line changes to initial conditions and programmed exercise parameters.

The training capabilities of both alternatives are the same. The instructor actions required to exercise the capabilities differ, and center around CRT touch panels versus console-mounted electronic touch pads. It should be noted that since CRT touch panels are used in both options and since the software and instructor support features are essentially the same, many of the operations are the same.

ADVANTAGES AND DISADVANTAGES

Alternative 1

Alternative 1 is characterized by minimum use of fixed-function electronic touch pads and maximum use of CRT touch panels. The emphasis is on simplicity of the IOS, and simulation monitoring and control via displays and their associated touch panels.

Advantages. As a result of the low number of fixed-function controls on the IOS console, the IOS is simple and compact. Also contributing to the compact design is the clustering of the CRTs into what is essentially a single-position station. The appearance of the IOS does not overwhelm new instructors. On the contrary, it presents a positive image for ease of operation.

The compact size of the IOS enhances the instructor's span of control and enables him to easily scan all controls and displays. All operations can be carried out while the instructor is seated at a single position. The station is designed to meet human factors specifications for reach envelope, instructor anthropometry, visibility, etc.

Alternative 1 takes full advantage of available control, display, and software state-of-the-art technology. Its design and operation are not driven by the technology. Rather, they are intended to take full advantage of what is available and in doing so to further advance the state-of-the-art in IOS design.

The software capacity of Alternative 1 provides for maximum flexibility in use of the trainer. Controls and displays are readily accessible through the software associated with the displays and touch panels. Efforts have been made to use concepts which minimize the number of decision steps in making selections. This results in increases in the ease of taking advantage of the design flexibilities.

Programmed scenarios, procedures, alternatives, etc., are readily updated through software changes. This flexibility is afforded through the use of variable-function touch panels, as opposed to fixed-function touch pads, and the use of a variety of software support features.

Disadvantages. Alternative 1 requires more software. This greater software requirement in comparison to Alternative 2 is necessary to enable scenario selection and control through a central master menu.

More initial IP training is required to allow full operation of the trainer. This training primarily involves use of the menus, familiarity with selection alternatives, and anticipation of decision points. Through proper programming and use of the IAS, and a limited amount of experience, it is anticipated that this disadvantage would be minimized.

In certain situations more steps are required to select desired displays and make data entries. The steps are required to branch through the menus and indices to access the desired end point.

Alternative 2

Alternative 2 is characterized by extensive use of fixed-function electronic touch pads on the IOS console. The touch pads serve the same functions as many of the menus, indices, and touch panel selection options in Alternative 1. The major IOS configuration difference is the prevalence of these electronic touch pads.

Advantages. Most of the basic simulation controls are located on the IOS console. They are, therefore, always available for observation, study, and activation. Through their presence and labelling many of the capabilities of the device are displayed without reference to manuals or the software.

The software required in Alternative 2 is less complex than that in Alternative 1. This results from the use of fixed-function electronic touch pads on the IOS console in lieu of menus, indices, and CRT touch panels which are used in Alternative 1.

Since many of the device controls and capabilities are "hard-wired" in the IOS console, IP skill and training requirements are reduced. It is anticipated that IOS familiarization training would be simplified, retention improved, and maintenance and upgrade of skills improved.

The use of fixed-function electronic touch pads, in many cases, minimizes the number of steps required to access controls and displays. The touch pads enable the instructor to go directly to the final selection index or the desired end display without branching through a sequential set of menus. Thus efficiency is enhanced.

Disadvantages. Alternative 2 contains a large number of fixed-function electronic touch pads on the IOS console. Even with a layout based on good principles of human factors, the IOS will appear cluttered and may in certain situations be inefficient to operate or lead to confusion. The clutter may have a psychological impact on instructors (i.e., the complexity of the device operations may appear overwhelming).

To accommodate the layout of console-mounted electronic touch pads, the IOS will be larger than that in Alternative 1. This increased size may affect the instructor's span of control and ability to scan the IOS controls and displays. It may also reduce the instructor's capability to conveniently control all operations from a seated position.

The greater use of fixed-function controls rather than software driven variable-function panels makes revision and update more difficult. Some revisions/updates will require hardware changes. These same revisions/updates in Alternative 1 would require only software changes.

Control of exercises is divided between two modes: panel-mounted electronic touch pads and CRT touch panels. It is anticipated that operations using the two modes will be less efficient than the same operations using a single mode (e.g., CRT touch panels in Alternative 1).

CONCLUSIONS

IOS design has suffered from the same malady that has plagued the design of many other pieces of sophisticated hardware: insufficient analysis efforts and data on which to base decisions. As a result, many previous IOSs have not been designed to facilitate training. They have contained the shortcomings discussed in this paper.

The primary conclusion of this paper is that the design of an efficient, functional IOS requires systematic application of a variety of human factors and training data. The alternatives presented previously resulted from such a process. Future IOSs should be derived through a similar analysis process in which candidate IOS features are systematically identified and assessed. Selection of features, operating procedures, and configurations should be based on ultimate goals of optimizing both instructor performance and overall simulator training effectiveness. The resulting usability of the device will provide for increased user acceptance and improved training system effectiveness.

Future IOS design improvement efforts should focus on expansion of the recommendations presented in this paper. Possible topics include (1) applications, limitations and values of specific instructional features (e.g., playback, performance measurement, and demonstrations), (2) refinement of the design principles and concepts, (3) extension of the design principles and concepts to other types of simulators, and (4) modelling the IOS design process.

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NEEDED: A STATE OF THE ART INTEGRATED LOGISTIC SUPPORT ACQUISITION STRATEGY

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ABSTRACT

If logistics concepts are to maintain pace with the constantly changing hardware and software spheres, innovative state of the art logistics acquisition strategies must be conceived, defined, and implemented. Logistic acquisition concepts in the past have served well those devices for whose support they were designed. They cannot, however, meet the challenges occasioned by rising costs, the increasing demand for more reliable life cycle support, and ever more sophisticated training device systems. These challenges, as well as others, can best be met by developing a best value, performance based, functionally oriented logistics acquisition strategy. Such an evolution will focus attention on the product, not the process, of the logistics support acquisition effort. In turn, this shift in focus will require both Government and contractor to relinquish certain traditional roles and to assume some unfamiliar responsibilities. The authors recognize that such an approach will cause some degree of discomfort to both Government and contractor personnel. However, they submit that just as technology has advanced from the vacuum tube to the integrated circuit, so must logistics advance from emphasis on the acquisition process to concentration on acquiring logistics products which will provide reliable life cycle support to training device systems.

Changes to our current procedures for providing training device support are being mandated by three persistent and omnipresent forces: (1) the cascading flood of technological advancements in all phases of electronics, (2) the escalating costs and decreasing quality of logistics support efforts, and (3) the unpredicable availability of technical personnel. Although the necessity for modernizing logistics support procurement methods has been recognized for years, few methodological improvements have been planned, designed, or implemented. The logistics community has far too long focused on the process, not the product of the logistics procurement effort. As a result, we find ourselves more and more involved in a game of "catch up" rather than in a role of leadership. Thus engaged, we have failed to assert the vital importance of front end planning for logistics support. The inevitable result has been the generation of conflict between "what is" and "what should be" in terms of training device and simulator support.

The pressure generated by this conflict is influencing people far removed from our situation to enter the arena of logistics decision makers. These people, who are located in all strata of responsibility, from training device user to the Secretary of the Navy, have a vested interest in the availability of training device hours, in the cost, and effectiveness required to provide this availability. They are telling us that our traditional procurement philosophies are no longer meeting their needs. Receiving little, if any, positive response from the logistics community, they perceive that such inaction indicates a lack of ability. Because of this communication gap, we now stand on the precipice of being told that a cure will be effected by eliminating organic support in favor of full contractor support.

Before discussing the changes that are required to upgrade our logistics acquisition strategies, it is imperative that we gain some insight into the conditions which have led to this need. Only through an understanding of the current situation can we appreciate the need for a logistics acquisition strategy which will control costs, provide more reliable support, keep pace with technology, and provide the proper foundation for organic or transition to full contractor support in the future.

It may be helpful to realize that this need is not unique to the training device and simulator environment. A recent Society of Logistic Engineers Newsletter contains extracts from an Acquisition Improvement Task Force Report on the Carlucci initiatives.[1] This report sums up three areas of failure in support and readiness throughout the Defense Department acquisition process. First, and well known to most of us in the logistics business is the lack of management emphasis and support given to logistics. The report states that "support is still running a poor fourth, after performance, schedule, and cost." Next, the report cites a lack of front end logistics analysis as being responsible for building in higher support costs from the very beginning. Finally, the report states that support areas suffer from inadequate procedures, organization, and technical capability. These weaknesses are aggravated in the training device world through a combination of a dinosaur like devotion to tradition and rigid Government procedures which govern almost all aspects of a training device procurement.

The traditional tendency for low risk procurements and the lack of flexibility in logistics acquisition procedures have been addressed at previous industry conferences and in other areas of the acquisition literature. However, such treatments have tended to stress the theoretical aspects of the problems using a broad brush approach. And regrettably, seldom has a positive, feasible alternative been offered as a possible solution to both present and anticipated problems.

It appears valid to state that we can no longer continue to do business as usual if we are to keep pace with the technology we are responsible for supporting. We can no longer continue to stress the theoretical aspects of logistics while giving scant attention to the dynamics of the market place. We can no longer continue to loosely apply the concept of integrated logistics support, while we allow each logistic specialty to go off in divergent directions. We can no longer force logistics and program managers into the role of simply coordinating between individual logistics specialties such as training, provisioning, publications, and others. We must provide our managers with the tools required to overcome these shortcomings.

But such tools will be forged only when we recognize that logistics planning must begin with and be accorded the same stature as functional descriptions, military characteristics, engineering specifications and other documents which are drawn up for the hardware and software. Only then will we be able to adopt and adhere to a state of the art, innovative logistics support acquisition strategy which is a truly integrated package. Our recommendations for accomplishing this start with a review of Department of Defense (DOD) Directive 5000.1 of March 1982, entitled Major Systems Acquisition, which states that a cost effective balance must be achieved among acquisition costs, system ownership costs, and systems effectiveness in terms of the mission to be performed.[2] The directive goes on to say that the acquisition strategy developed for each system should consider the unique circumstances of individual programs and that these programs shall be executed with innovation and common sense.

It is realized that Department of Defense promulgated this directive for major systems acquisition and that training devices are seldom considered major systems. Still the logic is no less valid for the procurement of training devices and simulators, particularly if a series of devices is being contemplated. Innovation and common sense must be the prime requirement in all areas, including logistics. What is a good logistics strategy for one device is not necessarily appropriate for another device. A logistics procurement strategy developed for a series of four, five, six or more devices is not appropriate for a one or two device buy. Obviously, the reverse holds true.

It is the responsibility of both Government and contractor personnel to recognize this and to develop unique procedures for each buy. The day of the boiler plate, cut and paste logistic package is long past. We believe that what is required in today's environment is the development and implementation of a state of the art logistics support acquisition strategy based on the guidance of DOD Directive 5000.1 and on the guidance of other directives such as the Defense Acquisition Regulation[3] which sets forth the basic legal doctrine defining the role of Government and contractor relationships; Office of Management and Budget (OMB) Circular A-109[4] which further defines these roles and explicitly recommends that the Government establish system performance objectives and allow the contractor to develop detailed design objectives. These recommendations are further defined, enumerated in OMB Circular A-76,[5] which outlines the Office of Management and Budget's policies of acquiring commercial products and services for Government use. Also germane is the Secretary of the Navy (SECNAV) Instruction 4200.27A,[6] which clearly defines the role of contractor personnel. These directives and policy statements provide the cornerstones for our recommendations.

If logistics personnel are to overcome their current problems and retain control over their own future, drastic changes in thinking are required. Today's logistics requirements call for reliable, cost effective life cycle support of the highly sophisticated and dynamic hardware and software subsystems which constitute a training device. To meet these requirements, the authors advocate a performance based, functionally oriented logistics procurement approach that focuses attention on the product, not the process, of the logistics support acquisition effort. This strategy is defined as a flexible, product based approach to procurement of logistics material and services which rests on the assumption that the device contractor is in the best position to determine the most cost effective and efficient method for development of the life cycle support for that device.

The Performance Based, Functionally Oriented approach differs from the present approach in two fundamental concepts. First is the concept that the only measure of satisfactory logistics performance is the effectiveness of the final logistics package in supporting the device. Time and effort should no longer be wasted in scrutinizing every aspect of the development schedule, in developing detailed plans for every conceivable element, in requiring reports for every contractor movement, for developing and maintaining detailed milestone charts, etcetera. These are tasks which are functions of the contractor and which the contractor must do if he is to meet his contractual requirements with an acceptable product. Government personnel should focus on the quality of the delivered product. Second is the idea that performance of the device for the 10 or 15 years it will be utilized is of at least equal importance to the 3 to 5 years it is in the development and manufacturing stages; thus, logistics considerations should be given equal weight in the request for proposal and in the evaluation and payment clauses of the contract.

From these fundamental concepts are derived three basic premises:

1. Logistics support is an integral part of device procurement and the contractor should be tasked with the full and total responsibility of providing a reliable and cost effective logistics support package.

2. With the proper incentive, contractors will respond to Government's logistics needs.

3. Government can provide this incentive by stipulating in the contract that a major amount of total payment will be withheld until logistic acceptance criteria are met.

These concepts are not new, but they have been neglected in the quest for sophistication. What may be unfamiliar is that the Performance Based, Functionally Oriented concept is based on the premise that if the Government provides the logistics requirements, establishes measurements to determine if those requirements have been met, and by using the common sense mentioned in DOD Directive 5000.1, refuses to pay for materials and services that do not meet the established criteria, contractual cost effective reliable life cycle logistic support will be forthcoming. Industry has the capability to respond; the Government needs only to develop and provide the proper stimulus.

Logistic support requirements currently vary from full organic support to full contractor support. The Performance Based, Functionally Oriented logistics acquisition strategy was developed to provide a flexible, non-complex method of satisfying varying logistics requirements. The Performance Based, Functionally Oriented concept provides the contractor an opportunity to utilize his creativity, technical expertise and common sense to develop an effective support program when given an established set of objectives in the logistic statement of work. The end result expected from the contractor is a cost effective life cycle support program which can be verified by the Government through evaluations of the performance and usefulness of people, equipment, and documentation against a set of measurable objectives.

The Performance Based, Functionally Oriented acquisition strategy consists of three phases: definition, performance, and acceptance. During the definition phase, the Government integrated logistic support team joins the engineering team in conducting a front end analysis. In conjunction with the engineering team and with project management, a firm maintenance concept is decided upon. Using this maintenance concept as the keystone of all future integrated logistic support planning, the integrated logistic support team works together to develop an integrated logistic statement of work that clearly delineates the aims, goals, and objectives that must be achieved if the required level of life cycle support is to be realized. To properly carry out the all important task of developing a logistic statement of work that will contain all the necessary criteria for performance measurement will require a major effort from each member of the integrated logistic support team. Each subsystem of the device must be analyzed individually and as part of the overall system. The integrated logistic support team will be required to thoroughly research all requirements and ensure that the criteria developed are needed, attainable, measurable, and comprehensive. Once this is done, the logistic statement of work becomes the driving force for the remainder of the contract.

While the definition phase is primarily the responsibility of the Government, the performance phase becomes almost totally the contractor's responsibility. Once the contractor receives the logistic statement of work, it is up to him to develop an integrated logistics support program using state-of-the-art techniques. Once the contractor develops and receives approval on his integrated logistic support plan, he will have no further reviews, approvals, or other interference from Government personnel. Looking at this from another perspective, he will no longer be able to depend on Government specialists to perform a large share of his work for him. Here, the Government should adhere strictly to the provisions of SECNAVINST 4200.27A.

The last phase, the acceptance phase, once again becomes the responsibility of the Government. Through a series of verifications and demonstrations, the Government will verify the contractor delivered product against the criteria set forth in the logistic statement of work and approved in the integrated logistic support plan.

DEFINITION PHASE:

During this initial phase, the Government integrated logistic support team members must engage in conducting a thorough front end logistics analysis. The time is past when logistics personnel could wait until the device became a conceptual reality and then build a support program around it. In addition to determining the logistics needs, the integrated logistic support team members must become technical advisors on all committees and other teams connected with developing front end documents. Such actions will ensure that logistics become an integral part of the device procurement.

Once the front end analysis is accomplished, the integrated logistic support team must utilize the logistic statement of work developed as a result of that analysis to prepare a request for proposal. The total integrated logistic support team should become involved in the development of the request for proposal to ensure that the package is totally integrated and supportable. In developing the inputs the team members must take into account the proposed training device, who is going to man the device as instructors, operators, maintenance personnel and above all, what is the maintenance concept/plan for the device. With these facts in mind the logistic team develops a list of terminal objectives outlined in a logistic statement of work which ensures that the device will be supportable to the required maintenance plan level. Next, the team develops the following procurement package inputs:

1. Funding Requirements.
2. Request for Proposal.
    a. Schedule.
    b. Final Logistics Statement of Work.
    c. (DD Form 1423) Integrated Logistics Support Plan Requirements.
    d. Technical Proposal Requirements.
    e. Proposal Evaluation Plan.

The technical proposal requirements take on a new meaning under the Performance Based, Functionally Oriented Program because the Government is no longer evaluating proposals based on yes/no responses. The contractor's proposal evaluation is based on how well he responds to an established criteria by applying state-of-the-art procedures. No longer will the contractor have a boiler plate set of guidelines that he can feed back to the Government as a logistics support outline in order to receive a satisfactory proposal evaluation rating. He must use his own skills, abilities, and techniques to determine the best approach in developing a logistic support program that is totally integrated and which will support the device during its life cycle.

The only logistic document required by the Contract Data Requirements List, DD Form 1423, during the request for proposal is the integrated logistic support plan. The integrated logistic support plan will outline the contractor's logistic support plan for the device and, among other items, will contain the contractor's recommendations for all other logistic documentation.

Proposal evaluation procedures will require a highly skilled professional logistics team with expertise in logistics management, the technical aspects of the trainer, and in specific areas of logistics. The evaluation will be accomplished in two parts: first, by a group of highly qualified technical specialists and secondly, by a joint logistic team to ensure that each element is integrated into a total logistic effort. This joint evaluation will assist the negotiation efforts and ensure a two party win-win situation that will help guarantee a quality product for the fleet.

PERFORMANCE PHASE:

The first step after contract award will be a series of conferences between the Government logistics team and the contractor to define the detailed requirements of the integrated logistic support plan. The primary reason for the Performance Based, Functionally Oriented Program is to create an innovative, flexible integrated logistic support system. Under this concept, the integrated logistic support plan becomes the keystone document which is meant to ensure that each training device is provided a quality support program. No longer will each specialist have his/her own management document governing a specific logistics area. All areas will be governed by the integrated logistic support plan. The integrated logistic support plan will be broken down into a specific set of sections which will be determined by the needs of the device. Specific sections that may be required are:

1. Introduction.
2. Management.
3. Maintenance Plan/Concept.
4. Personnel and Training.
5. Logistic Data.
6. Support and Test Equipment.
7. Supply Support.
8. Facilities.
9. Interim Support.
10. Transportation Handling.
11. Integrated Logistic Support Accountability.
12. Verification Demonstration Plan.

Sections 2, 11, and 12 will be discussed briefly since they will contain the specific requirements which are the essence of a successful integrated logistic support program. Section 2, Management: This section should spell out the integrated logistic support management program and how each logistic element will be integrated into the total support program to ensure that the logistic services provided are all to the same level. Section 11, Integrated Logistic Support Accountability: This section should be a plan spelling out how the members of the device team are going to account for specific items and funds to ensure that specific allocations are slated for a specific area and not diverted to another element without coordination with all concerned. Section 12, Verification Demonstration Program: This section should define how the Government is going to verify the contractor's performance.

Each section of the integrated logistic support plan will be a stand alone document for the management of the individual elements. When the sections are combined, they will form a volume which will provide a comprehensive integrated logistic support plan for the logistic manager. Each logistics specialist will be responsible for the development and acceptance of his/her specific section(s) within the integrated logistic support plan. With this method of developing the integrated logistic support plan, the logistics specialists will have the flexibility to manage their own specific areas and yet give the logistic manager the capability of total integrated logistic support management.

During the orientation conference, the Government will outline its interpretation of the contractor's proposal as it relates to the aims, goals, and objectives of the logistic statement of work. These differences will be reconciled during the conference. Upon completion of the conference, the contractor will forward the revised integrated logistic support plan to the Government for review prior to the integrated logistic support plan conference. Thirty days after delivery of the preliminary integrated logistic support plan, an integrated logistic support plan conference will be conducted. During the integrated logistic support plan conference, the contractor will define, in detail, his concept of the logistic program as stated in the integrated logistic support plan. At this time the integrated logistic support plan will be accepted and become the prime logistic support document for the life of the training device.

The function of the contractor during the performance phase of the device is based on the contractual agreements defined in the integrated logistic support plan. These functions will vary depending on the maintenance concept/plan, size of the device, USER's, and type of trainer. Once the integrated logistic support plan has been approved, the contractor assumes full responsibility for development of the logistics support program.

ACCEPTANCE PHASE:

The acceptance phase is the Government's responsibility in that the Government must establish the criteria against which the contractor's performance will be judged. These expectations must be stated in terms of performance based, functionally oriented aims, goals, and objectives. This is accomplished as described in the definition phase above.

The evaluation method utilized to certify program acceptability will necessarily vary from project to project since it is dependent upon the outcome of the front end analysis accomplished for each device. However, in all cases, the methods chosen will evaluate: (1) the ability of the personnel assigned to support the device to properly fulfill their responsibilities; (2) the usefulness of the support equipment such as tools, test equipment, automatic test equipment and diagnostics in enabling maintenance personnel to carry out the designated level of maintenance; and (3) the accuracy, quality and quantity of documents such as maintenance publications, vendor manuals, PMS documentation, training publications and other required drawings, documentations and publications.

Since the contractor has been assigned total responsibility for development of the total logistics support program during the performance phase, he is totally responsible for the acceptability of his delivered product. As stated earlier, the provisions of SECNAVINST 4200.27A should be taken literally and applied unequivocably:

> The Government may . . . obtain the (required) work by contract, providing two conditions are met: (1) the contract itself must ask for the finished product, only, and (2) the contract must be administered in such a way that control and supervision over the work and discretion as to the techniques which will be used remain solely with the contractor. . . . The intent of this statement is made explicit in the next sentence. . . . In other words, if the Government wants a building painted it defines the job, lets the contractor paint the building as he sees fit, and then accepts it or rejects it solely on the basis of whether the completed job meets the contract specification. . . .

Thus, if the contractor has not lived up to his contractual agreements, he alone will be financially responsible. He will be assessed a significant portion of the overall contract amount for his failure to perform. This assessment may then be used by the Government to correct deficient areas through other means or to obtain, through agreement with the contractor, extended contractor support until the contractor can correct his own deficiencies. The authors believe that, since a training device which lacks satisfactory support is no more useful than a library without books, at least 50 percent of the total contract price should be assessed for failure to provide a satisfactory logistics support program.

SUMMARY

The rising costs, decreasing quality and flexible method of the current procedures for procuring logistics support for training devices have made changes inevitable. This paper has addressed several of these problems and has pointed out why fresh thinking is needed now. Obviously, there is no perfect solution to the multifaceted problems associated with providing reliable, cost effective life cycle support to training devices and simulators. The authors have proposed the Performance Based, Functionally Oriented Logistics Acquisition Strategy as a possible framework which can be embellished upon to achieve two important goals. The first is the immediate need to improve our logistic acquisition policies. The second is to provide a smooth transitional step into the era of full contractor support, which the authors believe is both inevitable and desirable given the predictable events of the future.

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SOME ANALYTICAL THOUGHTS ON ONE ANSWER TO THE ARMED SERVICES

TRAINING MANPOWER CRUNCH - TRAINING BY CONTRACTORS

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ABSTRACT

Numerous studies and discussion sessions have focused on the military personnel shortages extending through the year 2000. The manpower problem promises to be acute according to demographers, as government, industry, and the military compete for a share of the shrinking pool of young work-age personnel. Military personnel and training planners face an increasingly difficult dilemma on how to stretch their manpower to meet pressing combat unit requirements and, at the same time, to deal with greater training loads brought about by new weapons systems and high personnel turnover. The Services, particularly the Army, believe they need to reduce the number of personnel committed to the training function in order to free skilled and experienced key NCOs and officers for field duty.

This paper offers analysis suggesting one answer to this serious training manpower problem--more training performed by contractors. Training by contractors is certainly not new but it has been largely utilized in the past for limited, highly specialized, often one-time, training efforts associated with the introduction of new weapon systems. A broader-scaled contractor training effort might offer better training continuity, more professional staffing, ways to meet capital investment costs involving new sophisticated computer-based training equipment, and yet produce a quality trained technician in a cost effective and expeditious manner. A pertinent, limited case study provides illumination in this area. The paper also addresses the disadvantages and problems, such as inflated costs, associated with a contractor developed and run training program and suggests contractor responsibilities in this regard. The anticipated manpower crisis demands a search for solutions. An increased training role for contractors might ease the armed services manpower crunch while reducing the expected industrial competition for some of the same manpower resources.

INTRODUCTION

The demographic predictions about forthcoming national young worker personnel shortages are by now all too familiar. The problem in the 1990s whereby one-third of all 18 year olds will be needed by the military and whereby the military/worker recruiting pool would be 20 less than the 1978 peak has been aired in numerous Armed Services meetings and industry conferences, particularly, those relating to personnel and training. A year ago last May, the problem was an important item of discussion at San Diego during the first Annual Conference on Personnel Training Factors in Systems Effectiveness. At last year's [illegible] annual conference, several speakers addressed the subject. The discussion has been so extensive that one of the 1981 papers, by P.D. Maher of Hughes Aircraft Company, had as its title, "Military Personnel Shortages Through the Year 2000 - Enough Talk! Let's Do Something!!!"

As usual, "doing something" is considerably more difficult than reviewing and dissecting the problem. Nevertheless, a number of very positive proposals have been advanced. These include greater utilization of technology, such as simulators, interactive computer based training devices, interactive video disc systems, arcade games, robotics, and personnel electronic aids to maintenance. Such technology potentially could reduce system manpower requirements, decrease training times, conserve resources, and trim personnel supporting training.

Other ideas on meeting the manpower crunch have included the expansion or broadening of the workforce by greater use of women, postponed retirements, more extensive use of less capable people and, in the case of the military, the use of the draft.

Still other proposals have called for enhanced worker/serviceman productivity (particularly during the early years), improved selection and retention of personnel, and better engineering design in weapons systems to reduce or eliminate manpower requirements. At the same time, the weapon system designers have been urged to incorporate extensive human factors front end analysis with respect to trainability, operability, and maintainability.

Many educators, educational psychologists, and researchers have called for expanded research in the area of training transfer in order to derive the most education/training efficiency possible in the shortest time and for the least money. The goal would be to keep the trainee in the training pipeline as short as possible and to make him more productive once on the job.

All these ideas have merit and need to be pursued. Obviously, there will not be one answer but a combination of many ideas that will be needed to meet the manpower and training requirements of the 1980s and 1990s.

ANOTHER ANSWER

With the thought that a multiplicity of answers will be necessary, yet another idea is offered toward easing the forthcoming crisis--a greatly increased training effort by contractors. Training by contractors is certainly not new. Many weapon system manufacturers by necessity must provide operability and maintainability training on their products. After all, they know the equipment and can train the technicians because they designed and built it. In addition, companies specializing in training services and training equipment have appeared throughout the country. These training businesses have garnered training contracts from both industry and the military. Primarily, what is being suggested here, however, is that the scope of the current effort be notably increased and that the military consider contracting out their training effort in areas not previously thought appropriate for non-military hands.

Several strong and cogent arguments can be made for this proposal. First, a stronger and more comprehensive contractor training effort would free key, critically needed, experienced, highly skilled non-commissioned officers and officers for field duty. These personnel are usually the "cream-of-the-crop" in the Armed Services and placing them back into field leadership positions greatly enhances military readiness. The services have actively sought ways to reduce their military training staffs, partially to reduce training costs but mainly for the aforementioned reason. Recently, the U.S. Air Force has strenuously complained about the relative high proportion of inexperienced airmen in complex specialties.

Second, better training continuity will result with a more stable contractor staff. The Armed Forces with their rotation of personnel to overseas positions, and even with stateside assignments, inherently have a continuity problem. Considerable effort must be expended to prepare military instructors for their training responsibilities. Often the new military instructor must be sent to special contractor offered courses (sometimes called Type I training) on new equipment. Thus, maintaining continuity is a costly and time-consuming problem for the military.

Third, a contractor training effort would provide a high technology, state-of-the-art approach to training without the large capital investment. in similar programs being required by the Armed Services. Many companies and corporations have heavily invested in sophisticated interactive computer based video disc training systems both for commercial selling of training and to strengthen their own internal training programs. The 31 May 1982 issue of Aviation Week provided an excellent example in its article concerning Boeing Company's approach to flight and maintenance training for its new generation of transports. The thrust of the article was Boeing's efforts to use new technology (simulators and computers) to simplify the training of pilots and mechanics. Most companies, like Boeing, would welcome greater use of their expensive instructional systems at company training centers. The military could contract with a commercial firm utilizing their advanced computer based, video disc equipped learning centers to accomplish specific training tasks. Contract training, however, should not be viewed as simply sending the military trainee to a company. There may be many times when travel costs or other economic factors would dictate having the contractor administer training on a military installation. During the NSIA sponsored Army Training Technology Conference at Williamsburg, Virginia, in February of this year, a tour of the Army's helicopter maintenance training at Ft Eustis revealed several prime candidates for a contractor training effort.

Going one step further, taking training to the trainee in the field could, at times, best be performed by a contractor. Lt Gen Julius Becton of TRADOC has called for more study of reducing school time by field training. Dr. Davis S. C. Chu, Director, Plans, Analysis and Evaluation for the Secretary of Defense, has talked about contract support (which could include training) on board aircraft carriers, even in forward areas. Obviously, such contractor training would occur most frequently where small numbers of high skill technicians need training on a sophisticated piece of equipment. It is here that a contractor can make his most valuable contribution while holding down time in the training pipeline.

Still another argument for contract training is the more professional staffing that is possible. This is not to say that there are not quality military and civil service instructors, there are. However, the turnover problem often reduces the concept of training professionalism. Currently, in the ICBM force, as an example, training at the operating command level is being accomplished by technicians selected from the work force and designated "instructors." The fallacy of this procedure is (1) that manning documents are not structured to provide additional manning for "instructors," (2) the work force is effectively reduced and (3) although the "instructors" may be exceptional technicians, their abilities as qualified instructors may be seriously lacking and they may, in fact, be adding to the unit's training burden. In the military schools, the instructor is typically identified as a skilled technician first and foremost and only secondarily assumes the role as a trainer/educator. He frequently has only one stint as an instructor. In contrast, a business involved in providing training services recruits and hires an experienced instructor who is expected to continuously exhibit the trademarks of a competent training professional.

Turning more to contract training during the manpower crunch period would also ease the industrial/military competition for the same individuals in the dwindling pool of technicians and training professionals. The numbers might not be large but, because of the skills involved, they would be significant. Any stretching of the manpower resource will be important.

Unfortunately, as with most proposals of this nature, there are disadvantages that must be weighed. Most formidable, at least at first glance, is the cost that contractor training would entail. Because training would be openly purchased, costs would become supremely visible, like other parts of a weapon system. Some training associated with the introduction of a sophisticated new equipment, say a killer satellite, would be expensive indeed. A word of caution, however, Dr. David Chu points out that the cost of training conducted by the military does not always reflect indirect costs such as personnel retirement and inflationary (COL) increments.

Another disadvantage, associated with most procurement actions, is the loss of some flexibility. Changes in training programs could become more difficult because of contractual rigidities. Planning and requesting training would assume greater significance because time would have to be allowed for procurement procedures.

In addition, some will argue that the contractors cannot respond to wartime expansion requirements or, perhaps, not effectively train for war situations.

There may be other disadvantages but, like the aforementioned, they are not likely to counterbalance the gains offered by increased contractor training.

A CASE IN POINT

How might more contractor training work? Let us take the new M-X ICBM as an example. Currently, by contract considerable training planning is underway by various corporations working on this new missile. This large four stage ICBM incorporates new technology requiring extensive training for the training of ISD developers; instructors for Air Training Command, Strategic Air Command, and Air Force Logistics Command; Missile Test personnel; and the initial cadre for the operational base of the deployed missile. The military ISD developers, instructors, and initial cadre personnel are expected to plan, to assemble, and to execute a training program to satisfy the manning needs for the new weapon system by 1986. This is essential and good but it doesn't go far enough.

What makes greater sense, particularly in light of the anticipated shortage of skilled technicians, is for the contractors to carry their training planning into action. When the Air Force lets the weapon system contract or contracts, a complete training package should be included. Not only would contractors plan out they would complete the ISD process and then conduct the training. The contractors, like Martin Marietta in M-X, have by necessity organized and administered a training program for their own personnel. The training staffs and courses have been assembled and training initiated. Instead of training Air Force personnel to train other Air Force personnel, the contractor would then build on the contractor training already underway and assume the whole training burden. In addition, the current System Requirements Analysis and Logistics Support Analysis contribute greatly to the ISD effort in effect negating the need for the long, costly ISD development by the military. In the case of M-X, the contractors would provide the training for the initial operational base personnel and any necessary follow-on training to support the operational missile. In other words, the contractor or contractors would provide complete educational training services thereby freeing military men and women for other duties.

In brief, what is being suggested is that the Armed Services let the contractors build their training program as they also build the hardware.

IMPORTANT CONSIDERATIONS

Whether the contractor training effort is part of the development and deployment of new weapon systems or the contracting out of an ongoing military training program, certain elements must be stressed to insure success.

First, contractors must deliver and maintain professional, quality training. As with any purchase agreement, the customer, in this case the nation and the Armed Services, has a right to expect that, after training, defense personnel will be able to perform their ever increasingly complex tasks. This means the contractors must institute rigorous quality controls over training just as expected on hardware or software. No slipshod training can be tolerated. Because of the nature of the educational process and the sensitivities of educators to the imposition of quality standards, this is not as easy as it sounds.

Second, contractors must implement stringent cost disciplines in their training programs. As previously noted, businesses involved in training can often take greater advantage of new technology to strengthen, speed, and enhance the efficiency of their training. At the same time, restraints must be exercised in continual procuring of newest state-of-the-art training equipment, thereby constantly escalating costs. Similar to designing, the temptation of over-engineering must be avoided. To make it possible for the Defense Department to contract for training, costs must be kept realistic and with appropriate justification. Also, contractors need to be prepared to offer "life cycle" costs in their training proposals.

On the other side of the coin, the Defense Department should fully consider and weigh all costs associated with military manpower, including such elements as retirement and inflationary pay increases. This becomes important when assessing or comparing the economics of training conducted by the military with training conducted by industry.

A fourth consideration is the matter of responsiveness to training requirements. Not only must contractors plan and prepare to offer training packages, along with their weapon systems, they need a receptivity and capability to adjust to changes in on-going training programs. One of the major problems in military training has been the many fluctuations in the flow of personnel through the training pipeline. It should be kept in mind that training people will forever be a dynamic enterprise and contractors involved in this enterprise must recognize this and maintain a greater flexibility than normally considered with contractual specifications.

A fifth factor needing consideration is the outlook of Defense personnel toward contracting training. Defense officials will need to be more open to proposals in this regard, including training exclusively and traditionally thought of as administered only by military units. In some cases, traditional military training programs could be broken down into parts, some of which, especially combative or security sensitive, would remain militarily conducted, while others would be handled by commercial firms. In the last few years, there has been a definite gain in the receptiveness of high officials but this must be extended to lower levels in order to make a bigger impact on the manpower problem.

Sixth, serious thought must be given to more automated tutorial type training for recurring and long-range programs. The military services commit important resources to administering training that is required on an annual basis. Contractors could step into this picture with a valuable service. Because of the often low priority of these training programs and the need for the most economical training possible, commercial firms would need to rely on technology intensive (individualized interactive video disc) versus labor intensive approaches to this training area. In concept, a contractor run learning center would offer a self-paced training package to the trainee who progresses with little supervision to a test and final fulfillment of the training requirement.

Finally, contractors, just as their military counterparts, must continually tie training to mission effectiveness. Since we are talking basically about military training, the question should forever be raised, "What happens in a wartime situation?" Is the training pertinent to war needs? Can readiness be maintained and can a fighting effort be sustained? What about surge training capacity to support larger war forces? Some individuals have called attention to this point, like Dr. Arthur Siegel of Applied Psychological Services Corporation, who takes a dim view of all the talk about simulation behavioral modeling that cannot reflect wartime requirements. Likewise, all contractors must look critically at their training in the same regard. To paraphrase an oft quoted remark, "We don't want to build the best training system that can be built and then have a war come along and ruin the whole thing."

The foregoing discussion suggests yet another way to respond to the nation's forthcoming manpower crisis. It is clear a multifaceted solution to this difficult problem is needed and training by contractors can be part of the overall, workable response. It does offer a number of significant advantages. At the same time, its effectiveness could depend on a variety of factors. With their careful consideration, contractor training could help promote teamwork, instead of deadly competition, between government, the military, and industry in stretching limited people resources. A far broader-scaled contractor training effort could thus be a significant contributor to a solution of a national problem while producing quality trained technicians or operators in a cost effective and expeditious manner.

ABOUT THE AUTHOR

Dr. Jack Ballard is a Logistics Engineer and training planning specialist in the Denver Aerospace Division of the Martin Marietta Corporation. He is currently responsible for training planning for several areas associated with the incorporation of the M-X weapons system into the Air Force's strategic systems. He holds a B.S.E. degree from the Univeristy of Arkansas, a M.A. from the University of Southern California, and a Ph.D. in History from U.C.L.A. He was formerly Chief of the Plans and Requirements Division of the Air Force's Lowry Technical Training Center where he was responsible for training preparations for the introduction of new equipment, such as the avionics packages for the F-15/F-16, into the military inventory. He also served as an instructor at the Air Force Academy and was a senior military training advisor to a Korean Air Force Training Wing. He has written a number of historical articles, particularly related to military/aviation history, and serves on the evening teaching staff at the University of Colorado at Colorado Springs.

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THE PROCUREMENT COMMUNICATION GAME

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ABSTRACT

Effective communications between Government and Industry, so necessary for a successful procurement effort, have often been missing in the past. This has resulted in cost overruns, unrealistic approaches and expectations, missed schedules, and finally unuseable and inadequate deliverables. In this, the Age of Atari, the training community has used the game approach to successfully train personnel in many areas. This paper uses that same approach to reach both Government and Industry in an effort to remedy the communication situation. The game is based on some of the milestones which occur during a procurement. The rules are the policies and guidelines which both players must consider to progress toward the game's end. Both Government and Industry win through the exchange of information, increased communication, and team effort. In conclusion, it was found that effective communications are an essential key to success in the game.

SECTION I
INTRODUCTION

The procurement cycle, as both Government and Industry know it today, is often full of misunderstanding, finger pointing, and adversary relationships. Each side in this conflict traditionally spends far too much time in trying to determine who is right, rather than moving forward in a joint, mutually beneficial effort to resolve procurement problems. Effective communication from both sides which could increase the likelihood of successful contract completion is often missing.

The purpose of this paper is to aid both the Government and Industry in achieving more effective communication in this area, specifically during the procurement cycle. The approach taken has been to present the problem in a game format.

The name of this game is PC (Procurement Communication). Everyone can participate in this type of game. There are no limits on the number of players, but they are generally grouped into two teams, Industry and Government. The goal of the Government team is "to obtain a good product for a fair price," while the goal of the Industry team is "to obtain a reasonable profit."

The game setting is the Acquisition arena. The object of the game is for a team to successfully progress through five procurement milestones:

- Requirements Definition
- Request for Proposal
- Contract Award
- Post Award
- Modification, Completion or Termination of Contract

Each milestone has its own peculiarities and associated policies which will present a communications challenge to all the participants. The risks for each team increase as they progress through the milestones.

The game consists of five innings. The Government is the visiting team. Industry is the home team. Each team will have an "up" in every inning.

To keep the game interesting, there are a few constraints to be considered. On the Government side of the board, one constraint was aptly described in a theorem by B. Schemmer, Editor of the Armed Forces Journal:

> "When faced with a 20-year threat, Government responds with a 15-year program in a Five-Year Defense Plan, managed by 3-year personnel, funded with single year appropriations."

On the opposite side of the board, Industry often has high mobility of personnel during a procurement cycle. Those that understand what is required and desired in the beginning are not necessarily those who execute the contract.

Communication difficulties between Industry and Government merely add to any existent problem. Through use of the PC Game approach and effective communications, Government and Industry can both become "smart players" and end up a winning team.

MILESTONE # 1
REQUIREMENTS DEFINITION

The Government is continually considering new requirements for procurement. Mastery of Milestone #1 requires that Industry be advised of these requirements. The methods by which the Government makes its requirements known to Industry are varied. One approach is the annual Interservice/Industry Training Equipment Conference, which presents a perfect forum for advising Industry of Government's requirements. Last year's conference was attended by 668 Industry and 461 Government representatives.

The Government strives to improve its procurement practices through various methods of communication. An excellent example of this was a series of three conferences (Atlanta I, II and III) held by the U.S. Army material acquisition community in May 1974, February 1975, and May 1976. Industry representatives met with Army representatives to review an Acquisition Process that was beset with many problems. Communications flowed freely and this was quite evident by the tone of Major General George Sammet, Jr.'s comments:

> "Late in 1973, the Army's Acquisition Process was an object of increasing criticisms. The process was viewed as cumbersome, nonresponsive, and layered with bureaucracy that either couldn't or wouldn't perform. Criticisms came from every quarter.
>
> We didn't like what we heard and didn't believe it. No manager likes criticism.
>
> Nevertheless, the perception that we were not effective and were hard to do business with remained. Whether this perception was indicative of the true state of our acquisition capabilities or not, something had to be done. We did suspect that the outside world saw all of our weaknesses, and little of our strengths.
>
> We decided the best course of action was to get this problem out in the open and meet directly with most of our severest critics - our industrial suppliers."

Twenty-one acquisitions/initiatives were established at these meetings. One of these initiatives, Acquisition Initiative No. 6, "Advance Research and Development (R&D) Information," recommended release of planning summaries (less funding data) and the conduct of advanced briefings. Based on the results of these three conferences, the Project Manager for Training Devices (PM TRADE) established a policy whereby their requirements documents would be released to Industry on request and briefings would be conducted informally within reasonable limits considering workload, availability of personnel, and factors of that nature.

However, before this information can be furnished to Industry, the Government must have accurately defined their requirements. Requirements should fulfill user desires and at the same time be technically feasible and affordable.

Meanwhile, before Industry can master the Requirements Definition Milestone, they must establish their corporate performance objectives and policy guidelines, as well as recognize where their capabilities lie. Performance objectives include the determination of the type of market, possible market share, anticipated dollar amount, and return on investment (ROI) desired. Policy guidelines relative to quality assurance, pricing, public relations, advertising and financing must be decided.

Once these objectives and policies are established and corporate capabilities are recognized, Industry must then obtain information about the present and future characteristics of the Government market. At the same time, they must further their own capabilities through independent research and development, updating of resident skills and/or experience through other contracts.

Milestone achievement is now measured. In the top half of the first inning, the Government is asked the following questions:

1) Have the requirements (not just a wish list) been accurately defined?

2) Has Industry been informed of the requirements?

3) Are the requirements achievable with state-of-the-art technology?

If the answer is "no" to any of the three, the side must retire. To continue the game and reach the milestone, the requirements must be redefined, Industry must be informed, and the technology must be available. The game continues when all answers are "yes".

In the bottom half of the first inning, Industry is asked the following questions:

1) Have performance objectives been determined?

2) Has the marketplace been identified?

3) Have corporate capabilities been expanded and updated?

If the answer is "no" to any of the three, the side is retired. To continue, corporate performance objectives must be determined, the marketplace where company capabilities most fit must be identified, and capabilities must be updated and expanded. The game continues when all answers are "yes."

Lack of communication with Government as to actual requirements may cause Industry to waste money in the wrong areas and elevate overhead rates, causing them to no longer be competitive. INDUSTRY LOSES.

If Government fails to communicate its requirements to Industry, research and development efforts may proceed along and not meet the needs of anyone. The GOVERNMENT LOSES.

Effective communication can turn this into an "EVERYBODY WINS" situation where Industry keeps Government informed on the state-of-the-art, as well as new research breakthroughs. In return, the Government will be able to plan developments around the latest technology while keeping industry apprised of the requirements.

MILESTONE # 2
REQUEST FOR PROPOSAL

The next play belongs to the Government, who formally communicates with Industry by publishing a synopsis of an impending procurement in the Commerce Business Daily (CBD). This [illegible] prospective offerors an equal opportunity to participate in the acquisitions.

During this milestone, Industry must obtain as much information on the Government's requirements as possible. This includes military philosophy, weapons or system requirements, declining or expanding markets, and general "G-2". Industry must obtain guidance to optimize selection of biddable RFPs, which will maximize the ROI and utilize capabilities and available facilities. Sufficient advanced lead time in relation to the RFP can only be obtained through good communications with the Government as to its purpose and requirements as defined in Milestone 1. This intelligence can improve Industry's competitive position. Analysis of the Government requirements can aid in any Bid No Bid decision that must be made at this time.

The Request for Proposal (RFP) is a major acquisition link that must be carefully prepared by the Government. Important documents embedded in the RFP are the Statement of Work (SOW) and the Specification. These documents should be accurate and non-ambiguous, since they define the level of effort required of the offeror to accomplish the task. They also play a significant role in proposal evaluation, and ultimately become the standard for measuring the Contractor's performance.

Industry's answer to the RFP requires several types of communication. Within each corporation, the approach must be clearly communicated to all proposal writers. The requirements must be understood before they can be answered in a technically acceptable manner. Industry proposal writers must inform the Government of the offeror's intentions in a manner which cannot be misunderstood or misread. At the same time, they must persuade Government that theirs is THE best approach. Developed "Should Costs" must be accurate, and pricing inputs must be realistic.

The Government must avoid providing any information relative to proposed or contemplated acquisitions to any prospective offerors without providing it to all, since it might give them an advantage over other offerors. Not playing by these rules may earn the Government team a stiff penalty, since all prospective offerors must be provided exactly the same information.

A Pre-Proposal Conference is sometimes held to assure that the scope of work is understood or to clarify portions of the RFP. The questions and answers are recorded and furnished to all the offerors. Requirement weaknesses or ambiguities are sometimes revealed at this stage, and a formal amendment must be made to the RFP. Such changes to the solicitation package must be furnished to all firms.

The Government is responsible for safeguarding all information contained in an Offeror's proposal. This includes bids, quotations, descriptive literature/material or special technical data. In addition, any discussions held with offerors about their proposals must not disclose information relative to any other competing offeror's proposal.

Information provided in the Industry response to the RFP is privileged and confidential. When it is provided to the Government in good faith, it is assumed that Government eyes only will view it.

In the top half of the second inning, the Government must answer the following questions:

1) Is the RFP accurate and non-ambiguous?

2) Has the same information been furnished to all prospective offerors?

3) Has all contractor confidential information been safeguarded?

Any "no" answers cause the side to retire. The milestone can be achieved by clear and concise wording of the RFP, by assuring that all prospective contractors receive the same information, and by safeguarding the confidentiality of contractor-furnished information.

In the bottom half of the inning, Industry must answer the following questions:

1) Has the bid decision been decided from a thorough analysis of available intelligence?

2) Has the RFP been answered in a manner which cannot be misunderstood?

3) Have realistic costs been proposed?

Any "no" answers cause the side to retire. The milestone will be reached by using all information available to make the decision to bid, by understanding the RFP and answering it in a non-confusing manner, and by accurately projecting the price of the project.

An offeror in developing proposal costs must be very careful. Proposals that are too high may be non-competitive and proposals that are too low endanger potential profit. Either way, the OFFEROR LOSES.

Whenever Government fails to communicate its needs to Industry, the results are an item of insufficient quality (performance) or a higher than anticipated cost. The results can be equally undesirable if Government fails to understand the proposal from Industry. If such a proposal is accepted under a cost type contract and runs significantly higher than envisioned, added costs result. The total liability was not understood, and GOVERNMENT LOSES.

Both GOVERNMENT and the OFFEROR CAN WIN, through their ability to effectively communicate via the written word.

MILESTONE # 3
CONTRACT AWARD

Prior to contract award, an in-depth evaluation of all proposals received must be performed by a Government team of experts. The evaluation must be thorough, unbiased, and in accordance with the factors provided by the RFP. Industry must have confidence that the Government will follow the stated plan.

Offerors must sometimes provide clarification regarding specific areas of a proposal. Some proposals are found to be unacceptable when they fail to address the salient points of the RFP. Following clarifying discussions, offerors may be asked for their "best and final offer".

Following evaluation by the Government, the successful offeror is notified and a formal notice of contract award is published in the Commerce Business Daily.

The next major communication area is the negotiations which are conducted in accordance with strict procedures. The purpose of negotiations is to allow complete understanding regarding what the offeror proposes and whether it meets the Government's requirements, and finally to allow negotiation on the cost of the effort. The latter is of paramount importance, since the Government must be aware of its liability and the Contractor is concerned with a profit.

During inning number three, the Government must successfully answer the following:

1) Has the best contractor (who will supply best value) been chosen?

Obviously, the wrong choice here will result in a less than optimal procurement effort.

In their half of the inning, the winning Contractor must successfully answer the following:

1) Will we assure that the contract award was well deserved?

When both answers are "yes", the game progresses. The Government has successfully described its needs, and the Contractor has successfully described a method for meeting those needs.

MILESTONE # 4
POST AWARD

A Post Award Conference should be held at the Contractor's facility during the first month after contract award. Such a meeting can establish rapport between the Government and the Contractor. It sets the tone for an effective working relationship, advises the Contractor of the reporting requirements, and clarifies contractual points.

Informal communications can now proceed on a day-to-day basis at the working level. Reports, records, amendments to the scope of work, or delivery schedules are conveyed on a formal basis via the Government contracting officer. Any amendments related to deliverables or the scope of work can only be approved by the contracting officer. However, the contract also provides for various meetings between the Contractor and Government relative to particular program aspects which allow interactive communication.

Both Contractor and Government management must be effective communicators within their internal environments. Effective internal communications can lessen the possibility of external conflict when each team interfaces with the other.

By the time Post Award, the fourth milestone, is in sight, the Contractor should have his task or job clearly defined. The requirements of the RFP should be reduced to precise and detailed work statements. The Specification and any instructions necessary to undertake and complete the job should be understood.

It is now the privilege of the contractor to do the job as he sees fit within the limits of the contract. The tendency to ask for direction continually from the Government should be guarded against. Good internal communications must be established. Management should look to the written terms of the contract for guidance and to the Government contracts administrator for interpretation.

At the same time, the Government should be in a surveillance mode, not a supervisory one. It should not dictate how the Contractor is to perform, but rather assist the Contractor when necessary to ensure that, contractually, the Government receives what it bargained for.

Probably the single most important factor during Post Award is establishing informal communication between the Government and the Contractor at the working level. Initially, the Government initiates much of this communication to assure that the Contractor fully understands what is required under the contract. However, once work commences, a flow of progress reports and problem identification and resolution is communicated back to the Government from the Contractor. Such an information exchange is required for smooth progression of the effort.

During their respective turns in inning number four, the Government and the Contractor must reply in the affirmative to the following:

1) Have we established effective communication methods with our Contractor/the Government?

2) Are we allowing our Contractor/the Government to do the job we both agreed to during contract negotiations?

If there are minimal problems and there is ready resolution for existent ones, and effective communication methods have been established, the two teams can successfully advance to the next milestone.

MILESTONE # 5
MODIFICATION, COMPLETION OR TERMINATION

The fifth inning and final milestone are a culmination of all the pluses and minuses which have accumulated throughout the game for each team. The milestone can take three separate and distinctive forms, Termination of the Contract, Modification of the Contract, or Completion of the Contract. It is during this period that each team can judge the effectiveness of their communications; and retire from the game arena to lick their wounds, regroup, or successfully complete the procurement.

A variety of reports, i.e., progress or status, expenditures, achievement of specific technical directives, etc., constitute a formal record of the contractor's performance. These reports provide details of information already known to both parties. However, future actions of both the contractor and other Government agencies are based upon these reports.

The item developed under a contract must be tested in accordance with a formal test plan. A great deal of two-way formal and informal communications are involved in the process. When the item is successfully tested, the result is contractual progress. When the test is not successful, sometimes a modification to the contract is necessary. There are a few contracts that are not successfully completed but are terminated for various reasons.

Termination of the contract may be the disastrous result of a complete failure to communicate effectively. No meeting of the minds has occurred, no real understanding of the problems has happened, and each participant in the game must retire in defeat.

The middle ground between failure and success in the Procurement Game is contract modification. Through a breakdown in the communications process, the contract has gotten off the track. The game plan is then to repair the damage by reestablishing the communication link to permit redefinition of the requirements and rethinking the problem. Progress toward completion can then begin again.

If communications have been effective, the Contractor and the Government are now a team. The final milestone has resulted in victory for both, contract completion. The Government has obtained a good product for a fair price and the Contractor has realized a reasonable profit. Effective communications have made this possible, and both have achieved success.

CONCLUSION

As the Procurement Communication game progressed, neither the Government nor Industry could advance through the milestones without communicating with the other. Milestone #1 required that communication be established between the opposing teams. Success in continuing the game depended upon awareness by Industry of Government requirements and awareness by Government of Industry's technological gains.

Milestone #2 built on that initial communication baseline. Through effective communication, the Government team achieved success in the inning by publishing a clear and concise RFP while providing all offerors the same information and the Industry team achieved success by submitting a responsive and realistically priced proposal.

Milestone #3, Contract Award, marked the midpoint in the game. Negotiations required that effective verbal communication be established by each team so that the Government could assume that its needs would be successfully met and Industry, now the Contractor, could assure that the award was deserved.

Post Award required effective communication on the informal as well as the formal level by both sides. Success in Milestone #4 was keyed to communication by all team members to each other and to their counterparts.

When the two sides reached the final milestone, each had achieved its goal. The Government had its good product at a fair price and the Contractor had its reasonable profit. Playing the game and winning required an exchange of information that was thoroughly understood by both teams. Effective communications were an essential key to success in the game.

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A DSMC SIMULATION: DECISION EXERCISES

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ABSTRACT

In order to create a realistic learning environment for future acquisition managers at the Defense Systems Management College, a series of 20 case studies and 3 decision exercises have been developed to provide a scenario as close as possible to the real world of weapons systems acquisition management. A "womb-to-tomb" approach is taken: i.e., a mythical weapon system, System X, begins its life in mission-area analysis; has a gestation period culminating in a Justification for Major System New Start; then a development, production and deployment life; and finally is retired and disposed of. The system acquisition life cycle is the background structure on which the story-line for these cases is maintained. The Decision Exercises utilize the same story-line as the cases; they provide the student an opportunity to make systems acquisition decisions, then live with the consequences of these decisions.

DEFENSE SYSTEMS MANAGEMENT COLLEGE

The mission of the Defense Systems Management College is "...to educate acquisition professionals and conduct research, to support and improve Defense systems acquisition program mangement."(1)

The Defense Systems Management College (DSMC) is located in five, three-story buildings and includes a 400-seat auditorium on Fort Belvoir, Va., 20 miles south of Washington, D.C. Sixty civilian and military faculty members conduct the courses. Their efforts are complemented by guest lecturers from government, industry, and the academic communities.

The College program includes the 20-week Program Management Course, numerous short courses in specific functional areas, and several executive-level courses. The courses are intended to introduce the student to the world of systems acquisition, and to prepare him to function effectively within it. The content of each course is continuously monitored and altered, as necessary, to reflect changing real world conditions. New short courses are developed, usually in answer to the needs of a specific management group within the Department of Defense. The curriculum is updated to keep abreast of current management practices and to lead the development of new methods. Each faculty member maintains a close liaison with the military departments, other educational institutions, industry and business organizations, and professional societies.

The environment of defense systems acquisition is an ever-changing mosaic of requirements, budgetary constraints, technological capabilities, and political and strategic considerations. Preparing the manager to deal effectively within this environment requires a dynamic educational program that blends abstract concepts with real world experience. The courses offered by DSMC are designed to respond to this need. (2)

Program Management Course

The core of the DSMC program is the Program Mangement Course (PMC). It is attended by military and civilian students from all services, as well as representatives from defense industry. The PMC is offered to 200 students twice a year and includes courses in the functional area of program management: business, technical, organizational, and policy. To achieve integration among the various functional courses, a series of management case studies and computer-based decision exercises are utilized.

PMC Students

The Program Management Course is generally restricted to military officers in grades 0-3 to 0-5, DOD civilians in grades GS-11 through GS-14, and industry personnel identified by their companies as candidates for senior management positions. These are the norms, but requests for exceptions are reviewed by the DSMC admission committee.

In addition to meeting grade requirements, PMC students must be DOD personnel who occupy--or who have been selected to occupy--intermediate management positions in program offices, functional offices supporting program offices, or in higher-echelon offices supervising program management. Persons in equivalent program management positions in other federal agencies or defense industry are also selected to attend the Course.

The typical Program Mangement Course student is male, married, and 38 years old. He averages 14 years of military or government civil service, and is a Major or a GS-12. A majority of the PMC students hold graduate degrees, and have from 3 to 7 years experience in some aspect of acquisition management.

The School of Systems Acquisition Education, through four departments--Policy and Organization, Technical, Business, and a multi-discipline, integrating Management Laboratory--conducts the Program Management Course (Figure 1), as well as the short courses.

POLICY DEPARTMENT	ENGINEERING DEPARTMENT
o PROGRAM MANAGEMENT o DOD POLICY o BEHAVIORAL SCIENCE o EFFECTIVE COMMUNICATIONS	o SYSTEMS ENGINEERING o TESTING o PRODUCTION o LOGISTICS
BUSINESS DEPARTMENT	**INTEGRATION DEPARTMENT**
o CONTRACTS o GOVERNMENT FUNDING o INDUSTRY FINANCE o ESTIMATING/CSCSC	o SYSTEM CASE STUDIES o DECISION EXERCISE SIMULATIONS o STUDENT DECISION BRIEFINGS

FIGURE 1 PROGRAM MANAGEMENT COURSE

The Aquisition Management Laboratory

The Acquisition Management Laboratory provides experiential learning opportunities that integrate course material presented in the three functional departments.(3) The media used include a series of case studies covering the acquisition life cycle of a weapon system, computer-based decision exercise simulations, and individual student program management decision briefings.

System X

Systems X consists of a series of inter-related case studies involving a hypothetical weapon system. The cases simulate the life cycle of a weapon system through the concept exploration, demonstration and validation, full-scale development, and production/deployment phases. System X provides a realistic base for the discussion of typical problem areas encountered in program management. Group (5-6 individuals) analyses of case material are made, alternatives are studied, and a management position derived. The analyses are followed by section (4 groups) discussions, lead by a faculty case leader, that are intended to focus on the relevant issues and provide insight to the best possible course(s) of action.

Students work in heterogeneous groups designed with student interaction in mind. They are not afraid to present their views about situations created in cases or simulations, and to get involved solving acquisition problems with classmates.

DECISION EXERCISES

Students participate in a series of three Decision Exercises during the Program Management Course. The exercises attempt to simulate the real world environment of acquisition management.

Concept

The Decision Exercises emphasize issues and dilemmas concerning selected tasks possible in a program office during a phase of the acquisition. The student work group is asked to achieve consensus regarding decisions about these issues.

There are three such exercises, each intended to reinforce the lessons and concepts learned during classroom lectures and seminars, as well as System X cases. Decision Exercise I, for example, is a computer simulation paralleling the first six System X cases. The students establish a schedule of activities for the Concept Exploration phase of a weapon systems acquisition; then enter the schedule into a computer, and manage the acquisition of the weapon system; then enter the schedule into a computer, and manage the various activities as the system progresses through the phase. Decision Exercise II addresses the Demonstration and Validation phase, with Decision Exercise III addressing Full-Scale Development and Production.

The desired learning objectives of the Decision Exercise are:

o To enable the student to objectively analyze and quantify the complex issues involved in weapons system acquisition.

o To provide an understanding of the inter-relationship among organizations that play a role in the process.

o To exercise the student to make timely decisions that consider the complexities of these inter-relationships.(4)

Purpose

The first Decision Exercise simulates the Concept Exploration Phase activities from the submittal of the Justification for Major System New Starts (JMSNS) with the Program Objective Memorandum (POM) to Milestone I, the first meeting of the Defense System Acquisition Review Council (DSARC I).

Decision Exercise I Overview

The Decision Exercise is designed to be completed within a six-hour period, with a minimum of instructor supervision. The first one and one-half hours is devoted to an introductory lecture and group preparation (Pre-Exercise Preparation); then four hours to run the Decision Exercise program; followed be a half-hour for debriefing and discussion. The introductory lecture covers the desired learning objectives, group organization, allocation of time, and homework required.

The student's goal in this Decision Exercise is to get to DSARC I on time, within budget, and with the "best" concept(s) for continuation into the Demonstration and Validation phase. Throughout the simulation, the student team is faced with decisions that impact on schedule, budget, and personnel. Decisions are required in all the major areas of concern to a program manager.

Individual Preparation

Prior to beginning the Decision Exercise, each student completes four activities outside of class. They are required to:

1. Interpret the Justification for Major System New Starts (JMSNS). The student must select from a list of those factors they believe best describe the deficiency (Figure 2). The student group will weight each factor selected to the degree of relative importance.

AFFORDABILITY	PERSONNEL REQUIRED
APPROACH TO D&V	PRODUCTIBILITY
CORPORATION FACILITIES	RANGE
CORPORATION TECHNICAL EXPERIENCE	RELIABILITY
CORPORATION CONTRACT PERFORMANCE RECORD	SALT LIMITATIONS
COST TO SOVIETS FOR DEFENSE	SOCIO-ECONOMIC IMPACT
DETECTABILITY	SPEED
ENVIRONMENTAL CONSEQUENCES	SURVIVABILITY
FLEXIBILITY	SYSTEMS SAFETY
FORCE EFFECTIVENESS	TECHNICAL RISK
GROWTH POTENTIAL	TIMELINESS
LAUNCH VEHICLE REQUIRED	TIME TO DEVELOP COUNTERFORCE
MAINTAINABILITY	VERSATILITY
NATO RSI	WARHEAD SIZE

FIGURE 2 POSSIBLE EVALUATION FACTORS

2. Prepare a Program Objective Memorandum (POM) input. For the purpose of this requirement the student must submit a 5-year budget for his program. Resources made available to him are a cost estimating relationship (CER), a comptroller report, OMB inflation indexes, and an independent cost estimate (ICE).

3. Determine project office staffing requirements, i.e., the number and mix of military/civilian and technical/management personnel for the phase (Figure 3).

	MGMT/TECH	MIL/CIV
PROGRAM MANAGER/DEPUTY		
ENGINEERING	___ ___	___ ___
CONFIGURATION MGMT	___ ___	___ ___
TEST & EVALUATION	___ ___	___ ___
LOGISTICS	___ ___	___ ___
PROCUREMENT/CONTRACTING	___ ___	___ ___
PRODUCTION/MANUFACTURING	___ ___	___ ___
BUSINESS/PROGRAM CONTROL	___ ___	___ ___

FIGURE 3 PROGRAM OFFICE STAFFING

4. Schedule the major tasks and activities from the beginning of the Concept Exploration Phase until Milestone 1. The activities in the phase have been organized into 17 different tasks, some independent, and some dependent on others. Students are asked to organize and schedule these tasks and activities, then respond to prompting or leading questions, ranging from establishing and staffing the program office to preparing for the DSARC (Figure 4).

Group Preparation

In preparation for the simulation, students participate in a sample computer simulation exercise designed to acquaint them with the use of the computer terminals, available commands, and situations of the type to be expected. Immediately following, students are required to achieve concensus on the four areas they prepared--staffing, tasks, interpretation of the JMSNS, and the POM. This forms the basis for the group input at the beginning of the exercise.

The Exercise

When the exercise begins, a JMSNS for a Long Range Penetrator has been approved by the Secretary of Defense and the students have been assigned as "joint" program managers. They already have been given office space, hired secretarial help, and have an initial staff of five military personnel (2 managerial and 3 technical). The initial guidance is to determine

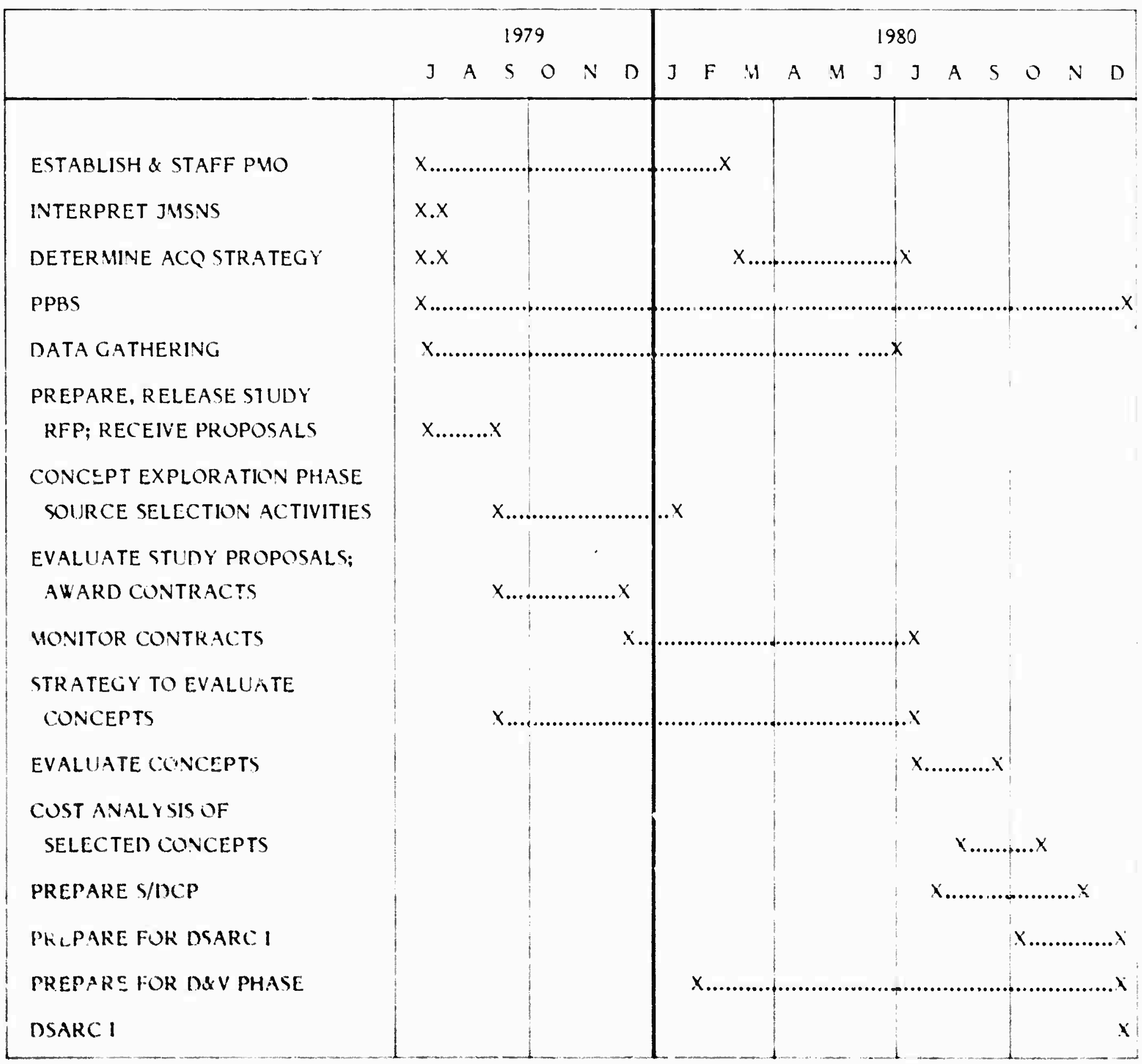

FIGURE 4 DECISION EXERCISE ACTIVITY SCHEDULE

the best solution to satisfy the documented deficiency. The DSARC is scheduled 18 months from the start time.

The distinction between military and civilian personnel staffing is made to simulate the time and cost associated with staffing a project office. Each task to be accomplished requires a preset number of one of those specialties (Figure 4). Prior lectures and seminars will have given the students an idea of what might be required, in terms of people, for each task.

For the purpose of the exercise each team is given a project budget and an initial allocation of funding for outside support, e.g. contractors, government labs, or outside agencies. The student team is first asked to enter their schedule of tasks and activities into the computer. Next, a particular task is selected by the student team; the simulation will either provide information, request a decision, or pose a problem. The simulation determines the number of days required to complete the team's selected action. The clock for that task is then set ahead by a specified number of days, dependent on the action taken. No further activity can take place in that task until the simulation moves forward to that time period.

For example, the task Establish and Staff Program Office is initiated early in the simulation. Students are informed of the personnel cost and time delays involved in staffing the program office with military and civilian personnel. The simulation asks for the number of military and civilian personnel the program manager wants. The team, through its response, is advised of the number of days that will be required by headquarters for processing approval of the personnel requests.

Sample Print-out

Establish and Staff Program Office

> Your program management office (PMO) is in the process of being organized. Your present staff consists of five military personnel. They are your technical advisor, two technical assistants, and two management assistants. At this time you should determine additional staffing requirements (exclusive of secretarial help) up to Milestone I. Once the staffing requirements are determined you will be required to submit a personnel request. Your budget expenditures for civilian personnel will be $32K per person per year. There are no budget costs for military personnel. Civilian personnel requested may begin arriving in as little as two weeks. Military personnel will be assigned within six to ten weeks after they are requested. At this time you should have your staffing plans for this phase firm.
>
> You may now enter your personnel request.

The program asks the student team to respond to prompts with the numbers of military technical, military management, civilian technical, and civilian management personnel they want to request. The next question provides them with an opportunity to correct their request.

> Are you satisfied with the personnel numbers you entered?
>
> Respond yes or no.

If they respond "no," the students are given an opportunity to revise the numbers of personnel entered earlier. If they answer "yes," the next question is displayed:

> Your staff has prepared a personnel request to be sent through appropriate channels. A response to this request is expected within a month. To send the request press "Return."

The student is then advised of the number of working days until Headquarter's review of the personnel request will be completed, at which time the following message is displayed:

> Your personnel request has been processed and the following numbers of civilian and military personnel have been approved:

The numbers of personnel approved in each category are displayed, along with civilian personnel costs for the next 18 months. These personnel costs are deducted from the approved budget.[5]

Equipment

There are 16 classrooms equipped for the Decision Exercise simulation; six students are assigned per room. Each simulation room contains two 1200 BAUD Hazeltine Executive 80 Model 30 "smart" CRT's with keyboard terminals, and one Centronics Model 704 impact printer. The terminals are configured so that either keyboard may be used to respond to the prompts from the program. All three devices (2 CRTs and 1 printer) display/print information simultaneously. In addition to the equipment in each simulation room, four terminals and printers are available in the faculty observation center. Each terminal can be used to remotely monitor student operations in any of four classrooms.

The Defense Systems Management College is currently under contract to the McDonnell Douglas Automation Company (MCAUTO) time-sharing system in St. Louis, Mo. A CDC Cyber 175 computer is utilized. Each Decision Exercise occupies 40-50K words of core memory; the program is written in FORTRAN IV.

Student Team Organization

The student team is advised to regularly alternate terminal operators and not to center group discussion activities around the terminal. It is also recommended that one member keep track of the progress of the Decision Exercise tasks so the group can anticipate which ones to proceed to next. The faciliatator's role during the exercise is essentially a passive one; he monitors the progress of each group and may stimulate discussion, but he does not get involved in the decisions.

Debriefing

The student team log file contains a history of the interaction between the student and the system during the running of the Decision Exercise. It is designed to provide the instructor with a summary of the completed exercise; it may be accessed whenever the student group has logged off the terminal. It records the actual and ideal start and finish dates, as well as elapsed time. A log is maintained of the budget and personnel used by the student team compared with the ideal. Additionally, student decisions made on key questions or problems which affect cost, schedule, or technical performance are recorded. An opportunity is provided for students to list comments directly from their terminal as the exercise progresses. The information in the log file is used by the instructor to debrief the student team. In the debriefing the student team is given feedback on how well they did in the exercise.

CONCLUSION

Based on our experience in conducting case studies and decision exercises at the Defense Systems Management College, we have found that students encounter a classical dilemma. They usually pass through the phase of (1) being overwhelmed initially by case study and decision exercise material, (2) realizing that one must pool efforts with contemporaries in order to succeed, and (3) eventually coming to the conclusion that the student has as good an answer as the instructor.(6) Students leave the Defense Systems Management College having improved their skills through functional instruction, as well as by experiencing the weapons system acquisition management environment through realistic case studies and decision exercises.

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REDFLAG SIMULATION: DEVELOPMENT OF AN INTERACTIVE, HIGH THREAT COMBAT ENVIRONMENT

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ABSTRACT

Flight simulators are being used to an ever greater degree to train combat related skills. The Air Force Human Resources Laboratory (AFHRL) has been tasked with determining the effectiveness of simulator training and providing guidance as to how to train for combat in a simulator. In order to provide these answers, high fidelity, realistic combat simulation must be accomplished. Using the Advanced Simulator for Pilot Training (ASPT), techniques have been developed for the generation of realistic combat environment scenarios. These techniques were used to develop an environment that closely models the Tonopah range at Nellis AFB, Nevada, a range that is often used for REDFLAG exercises. Advanced database modeling techniques were used to create the geographical features, cultural features, and provide low-level cues utilizing the maximum capability of the ASPT image generating system. The environment had numerous threats including surface-to-air missiles and anti-aircraft artillery. The pilot could interact with this environment in the same manner that he would interact with a real combat environment. Through the use of Radar Homing and Warning System (RHAWS) and the visual environment, the pilot could determine the location of potential threats and targets. The pilot could attack and destroy any target or threat within the environment and he could be "killed" by any threat. The environment simulation techniques that have been developed are very flexible and therefore the REDFLAG simulation can be quickly adapted to provide new scenarios.

INTRODUCTION

There is a critical need in the Air Force for realistic combat training. Studies have shown that if an aircrew member can survive his first 10 flights in the combat environment, his chances of survival are dramatically increased. These first 10 sorties represent the learning phase for the combat pilot. The Air Force currently trains pilots in combat skills through the various exercises that take place each year.

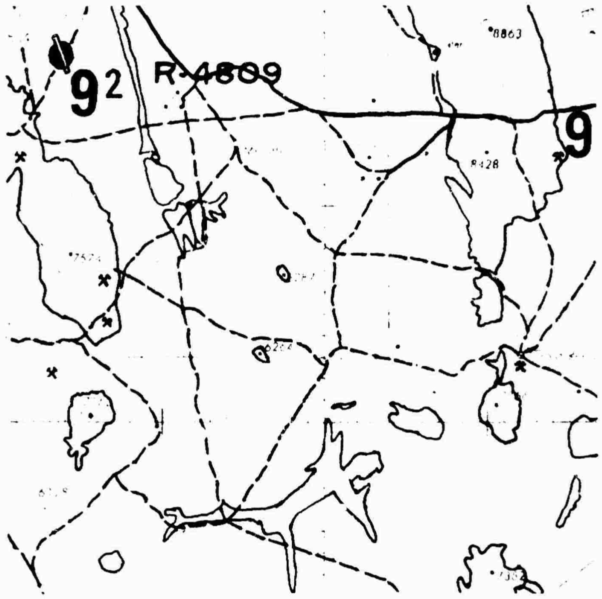
There are certain inherent disadvantages to these exercises. First, there is the loss of pilots and aircraft due to accidents. Second, there is a tremendous cost associated with conducting the exercises. Third, only a small percentage of the operational pilots get an opportunity to compete in an exercise at any one time. And last, the exercises do not constitute a continuous training but rather an occasional test of previously acquired skills. Flight simulators are not faced with these problems; however, the simulator has been faced with the problem of developing a realistic combat simulation.

Engineers and Behavioral Scientists with the Air Force Human Resources Laboratory at Williams AFB, Arizona, have been investigating the simulated combat environment. The primary tool used in this work has been the Advanced Simulator for Pilot Training (ASPT) located at Williams AFB. The ASPT has two cockpits, an A-10 and an F-16. The A-10 was used for this project. For details on the ASPT A-10 simulator, see Appendix A. As the focus of research being performed on the ASPT has shifted to the area of combat skills, techniques have been developed that allow for the simulation of realistic combat environments. The simulated REDFLAG described in this document was the first application of these techniques in direct support of simulator combat training research. The scenario chosen for the REDFLAG research study was comparable to a mission the subject pilots flew at an actual REDFLAG exercise. The intention of the study was to collect data that would provide a means of determining if there was a correspondence between the subjects' performance in a simulated REDFLAG mission profile and their performance in the actual REDFLAG exercise mission.

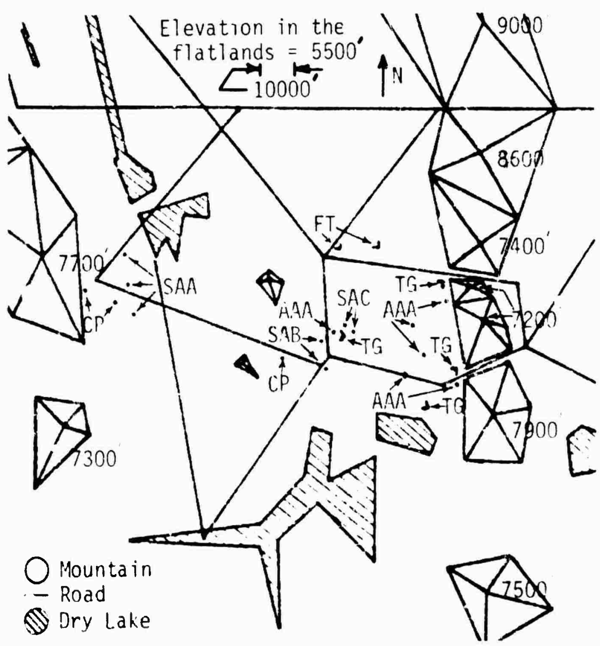
VISUAL ENVIRONMENT

Simulated environments are flat earth models of either real or imaginary places. Real terrain features such as mountains, dry lake beds, roads, and streams are depicted in abstract form in the simulated visual environment. Mountains are depicted by prisms shaped to correspond to the general contours of the real mountains they are intended to represent. Dry lake beds and fields are simulated by irregular areas of contrast on the ground's surface and are not associated with a change in elevation. Currently, roads are always composed of straight segments; curves are very expensive in terms of the image generation resources required to depict them.

The REDFLAG visual environment is a simulation of one of the Nellis Air Force Base ranges located southeast of Tonopah and northwest of Las Vegas (see Appendix B). Figure 1 is a partial Tactical Pilotage Chart of the area. Figure 2 is a map of the simulated visual environment with the locations of the targets indicated. The environment modelled includes command and control posts depicting real sized radar units, SAM and AAA sites, and tank



Tactical Pilotage Chart
Figure 1



AAA = Anti-Aircraft Artillery
CP = Command Post
FT = Friendly Tanks
SAA = SAM Type 1
SAB = SAM Type 2
SAC = SAM Type 3
TG = Tank Group

Map of the Visual Simulation
Figure 2

formations. Figure 3 is the visual simulation of a SAM. Figure 4 is the visual simulation of a Russian tank.

These vehicles are surrounded by a sea of random shaped rock-like objects, each 50 feet high. The REDFLAG scenario requires the pilot to fly a portion of his mission in the low altitude regime (see Appendix C). The vertical objects provide adequate visual altitude cues and do not exceed the displayable edge

SAM Threat
Figure 3

limitation. A continuing problem is getting the maximum number of cues using the least number of computer edges. Efficient 3-D cues, each having

Russian Tank
Figure 4

six edges, were used. The REDFLAG task required the pilot to maneuver his aircraft over a large area of ground. The vertical cues are placed in areas that would be used for ingress, egress, and threat evasion, and are placed 2000 feet apart, give or take 25%. Making the average spacing 2000 feet enabled the objects to cover a large area. The 25% variation is used to make the objects appear randomly positioned.

Finding a target using the 6 arc-minute ASPT visual system is a problem when the target is the size of a tank. The level of detail feature is used in an effort to correct this problem. When approximately 2-1/2 miles from a tank, the least detailed version becomes active. At about 1-1/2 miles, a more detailed version replaces the least detailed version. The most detailed tank becomes active at about one mile range. The least detailed version is made twice the size of a regular tank. The intermediately detailed version is 50% larger than an actual tank. The most detailed version is realistically sized. The other vehicles in the environment are handled the same way. The less detailed versions use fewer edges. This procedure made the targets large enough to be located from a somewhat realistic range.

Aerial View of Simulated Environment
Figure 5

The basic ground is a medium gray while mountains are shaded darker. Targets are generally medium dark. The vertical altitude cues and the roads are very dark. Dry lake beds are depicted using a gray shade that is lighter than the ground. Figures 5 and 6 are views of the simulated target area. At any given time, the environment will use approximately 150 edges for mountains, 50 for dry lake beds, 50 for roads, 500 for vehicles on the ground, 100 for a SAM inflight (there can be up to three visible at any time), and as many of the remaining edges as possible on the 3-D vertical visual cues.

The environment is modeled to depict accurately the actual REDFLAG area as nearly as a 2560 edge capacity permits. Every potential viewpoint was carefully considered to see that the maximum number of displayable edges were being used. The visual environment simulation operates synchronously with a set of threat simulation programs. The pilot is able to locate and kill a target while, at the same time, the target might kill him.

Aerial View of Simulated Environment
Figure 6

THREAT SIMULATION

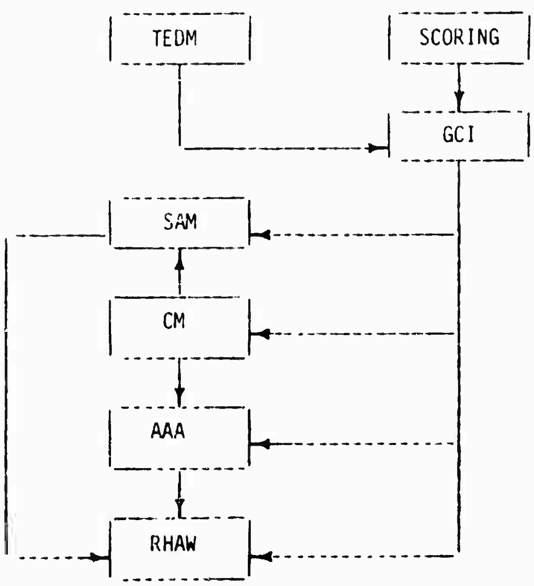
The programs which drive the threat simulation require information which describes the threats' environment in a fashion consistent with the manner in which they operate. Any specific threat site has its own perspective and experiences the environment only in terms of what it can "see" from its point of view and within its capabilities.

In the "real" world, threats "see" their environment through the information brought back via returning radar signals, infrared signals, or visual line of sight depending upon the system. In the simulator, this information must be provided in an entirely different way. Since the programmer knows where the threats are in the environment, the areas each threat will be able to "see" can be predetermined, given the known capabilities of the threat. In combat environment simulation, the limits of what each threat site is able to "see," i.e. its horizon, is defined in terms of two parameters called the maximum effective range and the minimum look angle. The meaning of maximum effective range is readily apparent, but what is meant by minimum look angle requires some explanation.

The minimum look angle is found by determining the angle of elevation (measured from the ground up) below which a threat would not receive meaningful information. Two types of factors influence the value of this minimum look angle: system induced limitations and terrain induced limitations. System limitations include the mechanical limits of the antenna scan and its susceptibility to ground return. Terrain limitations are imposed by the proximity of mountains to the threat site. The presence of a mountain within the line of sight increases the minimum look angle for all ranges beyond the mountain in that sector.

To define the horizon for each threat site, a polar coordinate "grid" is centered at each site. Each sector of the grid is bounded on the left and right by azimuth radials and the near and far side by concentric range rings. A single value for the site's minimum look angle is assigned to each sector of the grid. This requires that when a mountain contributes to only a part of the sector, its contribution is averaged on a proportional basis before determining what look angle value to assign to the entire sector.

The accuracy of the horizon defined in such a fashion depends on the interval between sample points along the horizon. Here a compromise must be reached between the simulation's realism and the available simulator resources. If a very small interval is chosen, the fidelity of the model is very good but the computer memory required is very large. Combat simulation requires that the correspondence between the visual environment and the threat's horizon defining data be close enough to allow the pilot to employ terrain masking in threat avoidance. Since the aircraft is in constant motion, it is possible for an approximation of the threat's horizon to suffice without losing realism.



Threat Simulation Module Structure
Figure 7

The threat simulation software is organized into a series of modules (see Figure 7) each of which performs a characteristic function. This structure allows easy modification of the method of implementing a particular function without necessitating that large portions of the supporting software be rewritten. What follows is a discussion of the basic functions and methodology of the major modules.

Since the threat horizon data are determined by location in a specific visual environment, it is convenient to place these data in a separate module. This is the sole function of the Threat Environment Data Module, TEDM. TEDM is an interchangeable module which contains all data that could be interpreted as scenario dependent. This includes the location data for each threat in the visual environment and some of the data determining the operational characteristics of the threat as well as the threat horizon defining data discussed above. This arrangement allows the threat simulation to be adapted to another combat scenario with minimum difficulty.

The logical heart of the threat simulation is the Ground Control Intercept (GCI) module. It uses data provided by TEDM and parameters defining the aircraft's location in space to determine which threats can "see" the aircraft. This is accomplished by calculating the bearing, range, and look angle from each site to the aircraft's current position and comparing them to the stored data that define the radar horizon for that site. As previously mentioned, the effect of local terrain is incorporated in the radar horizon data for each site. If the pilot approaches the threat using terrain masking, i.e., maintaining low altitude and/or keeping mountains between the aircraft and the threat, it is possible to get quite close to the threat without its becoming active. This capability is essential to realistic air-to-ground combat simulation.

Once the look angle test is satisfied, the threat site is activated. Threat activation consists of making an entry defining the nature of the site and its status in an array located in common memory. Data entered in the array tell all the user programs the status, location, and types of sites that are active. The nature of the data entered in the active threat array depends on the type of site. Basically each entry contains only data which are needed by user programs to drive the threat models. Site type and location are data that do not change within a given scenario; however, site status is highly time dependent.

A subsidiary function of GCI is the invocation of user programs in the proper sequence. Each user program may modify the data stored in the active threat array to further prepare it for use by other programs downstream. This is consistent with the modular concept by keeping all functions in the most appropriate module. For example, GCI will set the status of the Surface-to-Air-Missile site in either acquisition or track and will determine which of two otherwise equally active sites should be given priority for launch. It then lets the appropriate subroutine in the Surface-to-Air-Missile (SAM) module determine when to actually launch the missile from the site GCI has selected.

Once all sites have been checked, control passes to the countermeasures (CM) module. It checks for release of chaff and/or flares, then determines the effectiveness of the countermeasure selected. Effective countermeasures influence the operation of the SAM or Anti-Aircraft Artillery (AAA) modules by denying updated aircraft position and velocity vector data. Countermeasure effectiveness can be varied in many ways depending on the requirements of the research or training. In the REDFLAG simulation only chaff was available and each chaff release provided 3 seconds of effective chaff.

Upon completion of execution of the countermeasures (CM) module GCI calls the SAM module. Actually the SAM module consists of a series of subroutines each of which is responsible for driving a model of a particular type of surface-to-air missile. All surface-to-air missile systems are currently modeled in the same manner, i.e., the basic structure of the subroutine is the same for all models. However, each model uses different values for critical parameters such as maximum speed or turn rate so that the performance of the model reflects the capabilities of the system it represents.

Each SAM subroutine performs the same basic functions. First it searches the active threat array for threats of its type. Then it checks the status of each threat found. For threats in the aquisition mode no further action is necessary. For threats in the track mode the subroutine attempts to align the missile with the line of sight to the target aircraft. Once the missile is aligned it is launched and the subroutine guides it on a course intended to intercept the aircraft's flight path. While the missile is in flight, the subroutine continually checks the missile's proximity to the target to detect the moment of closest approach. It is assumed the warhead will detonate at closest approach. The distance separating the missile and the aircraft at closest approach, i.e., the miss distance, is compared to the kill radius of the missile warhead to determine if the aircraft has been destroyed.

Each subroutine in the SAM module is capable of handling several different threats of its type simultaneously. An exception is that only one missile of each type is allowed to be in flight at a time. This restriction is a result of the manner in which the REDFLAG threats were simulated. In the simulated REDFLAG three moving models were used to represent inflight SAM missiles; one dedicated to each type of missile modeled.

After the SAM module has executed GCI calls the AAA module. In the simulated REDFLAG, time elapsed since the aircraft came over the threat's horizon is the primary criterion governing operation of the AAA. A couple of seconds must pass before a site will recognize a target. Then a few more seconds will pass before the site will begin firing. A kill is determined by the amount of time the aircraft remains in the AAA firing envelope.

Both the AAA and SAM threat modules respond to evasive manuevers performed by the pilot. The SAM module subroutines react to aircraft manuevering when computing target intercept guidance and can be out-manuevered. The time required by AAA to kill the aircraft can be increased if the pilot executes a high-G turn while receiving fire.

The last module called by GCI controls the in-cockpit Radar Homing and Warning (RHAW) display. The RHAW informs the pilot of his exposure to threats using data supplied by the GCI, SAM and AAA modules via the active threat array. For the REDFLAG simulation a generic RHAW display was provided. Each active threat was shown on the face of the instrument at a clock position consistent with its bearing relative to the aircraft. The status (aquisition, track, etc.) and type (SAM or AAA) of each threat was indicated. However, no information indicating the highest priority threat or the specific kind of SAM was available to the pilot.

The results of the pilot's weapon attempts against targets are determined by the SCORING module. The SCORING module runs independently of GCI, but information identifying killed threats is communicated to GCI by scoring so that killed threats are deleted from the scenario. The REDFLAG visual environment contains numerous scorable targets. The scoring module must determine which of the possible targets the pilot is attempting to hit and report the results. To reduce the amount of processing required, a list of potential targets is formed from all those possible during the time between weapon releases. Potential targets satisfy three criteria:

1. They have not been killed previously.
2. They are in front of the aircraft.
3. They are relatively close to the aircraft.

When a weapon attempt occurs, SCORING selects the target closest to the weapon impact point from the list of potential targets as the target the pilot intended to hit. If the weapon attempt was a strafe pass, the miss distance relative to the target center and the clock position of each round is computed. The miss distance is used to determine if the round was a hit. At the completion of each strafe pass, the number of hits, total rounds fired and the distribution of rounds fired is provided on a CRT display located at the simulator operator's control console. For bomb releases miss distance and clock position are calculated and displayed.

The kill criterion in effect for the simulated REDFLAG was one strafe hit killed any target. A hit was defined as a round passing within 5 feet of target center. A bomb impacting within 150 feet of any target would also qualify as a kill.

CONCLUSION

Effective combat simulation could provide the pilot with the opportunity to learn, practice, and improve his combat skills in a safe and cost-effective manner. The methodology outlined in this paper significantly contributes to the capability to conduct research to determine what constitutes effective combat simulation and could provide the framework for operational simulator combat training.

APPENDIX A
ASPT/A-10 Description

The Advanced Simulator for Pilot Training (ASPT) is a research simulator originally designed with a full mission T-37 capability. A detailed description of the original device may be found in Gum, Albery, and Basinger, 1975 (AFHRL-TR-75-59). One cockpit has been modified to represent an A-10 configuration while the other cockpit has been configured as an F-16 aircraft. Neither of the modified configurations has full mission capabilities. Both systems were designed to have necessary cockpit and aerodynamic capabilities to support transition flight tasks such as takeoffs, approaches and landings, basic navigation tasks, and conventional air-to-ground weapons delivery tasks. Both cockpits are being continually modified to expand the capability for combat simulation and more closely simulate actual aircraft capabilities and characteristics.

The following is a description of the ASPT/A-10. The visual display is a monochromatic computer generated image displayed through seven CRTs with a 300° horizontal by +110° vertical field of view. The ASPT/A-10 also has a field of view of -20° over the nose, -40° over the left side, and -15° over the right side. There is a "G" seat/suit capability. The cockpit layout was designed to duplicate the aircraft in most major respects. Aircraft aerodynamics provide normal flight characteristics throughout the aircraft envelope and can provide characteristics for the Manual Reversion Flight Control System. The aerodynamic model does not account for weapon weight or station number but does account for weapon drag. All flight and engine instruments are operable, including the HSI. Communications panels are static mock-ups. The HUD provides displays for manual strafing and bombing. The weapons modeled on the A-10 are the BDU 33 and the 30mm cannon at the high rate of fire.

APPENDIX B
ASPT Visual System Description

The Advanced Simulator for Pilot Training (ASPT) Computer Image Generation (CIG) system stores the visual environment, defined in a three-dimensional reference system, in computer memory. The data are then retrieved and projected as a perspective image on a series of seven, 36-inch 1024 by 1024 CRTs.

Visual database modeling is the art of defining and storing the visual environment as numerical data in computer memory. Maps, photographs, and scale drawings are used as source data.

The CIG is composed of vertices defined mathematically in 3-D space. These vertices are connected by edges. The edges are used to make faces. The faces are assigned a gray shade and used to make 2-D or 3-D objects. The objects are used to construct models. The models are then put together to make the environment.

There are many limitations on the modeling of the visual environment. Faces must be convex with their vertices in the same plane. A face may have up to 16 vertices. An object may have at most 32 vertices and 16 faces. Models can have no more than 15 objects. In a visual environment there may be at most 300,000 edges, 40,000 objects, and 2000 models. The real-time visual system can display at most 2560 edges, 512 objects and 200 models in the frame time of 1/30 second.

The visible edges per system limitation are usually encountered first. Because of extra edges generated when edges cross window boundaries, the effective maximum edges used to make a visual scene should not exceed 2000. If the edge limit is exceeded, undesirable visual effects, such as priority problems and portions of the scene flashing in and out, occur.

The ASPT visual system allows three levels of detail per model. The switching distance from one level to the next is a function of the aircraft altitude above ground, the distance to the center of the model, and the size of the model.

ASPT uses shades of gray for painting the displayed faces. The scale goes from 0 (very black) to 63 (very white).

APPENDIX C
Low Level Modeling Considerations

Lack of adequate visual scene detail limits the usefulness of the Advanced Simulator for Pilot Training (ASPT) computer image generation (CIG) system for simulating low level flight. The visual environment modeler should optimize existing capabilities to compensate as much as possible for the lack of scene fidelity to better provide for the low level task.

Both ground texture patterns and vertical objects are used as primary visual cues by pilots in judging aircraft altitude above the ground. Ground texture patterns must be quite intricate in order to be effective. They therefore use a large number of computer graphic "edges." Ground texture can be used effectively without overloading the computers if a preset flight path is adhered to by the pilot. Vertical cues are more effective in a situation where the pilot is not required to fly a pre-defined flight path. These vertical objects provide a better altitude cue than a ground texture pattern composed of the same number of edges. A vertical cue can use as few as six edges. The cues are usually made much taller than they are wide to enhance their vertical appearance. These cues can be put throughout an environment up to the point of edge overload.

Environments can be set to work quite efficiently for a low level flight with models becoming active and inactive in a way that the system's edge limit is always being approached. The distance at which a model becomes active and then switches levels of detail is a function of the aircraft altitude and distance from the center of a model and the size of the model.

If the pilot must raise his altitude to turn or make a run on a target, the increased altitude can cause too many models to become active and thus overload the system. Under these circumstances, a trade-off must be found, usually by trial and error.

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TRIAD - AN APPROACH TO EMBEDDED SIMULATION

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ABSTRACT

Embedded simulation embraces the concept of using the real vehicle, artifically stimulated in a controlled manner, for the purpose of training operators in the use of the vehicle equipment. All the advantages of a controlled training environment, safety, malfunction training, etc. associated with dedicated simulation apply, together with greatly reduced capital costs and added operational flexibility. The paper describes TRIAD, a prototype simulation complex developed for helicopter pilot training that incorporates embedded simulation principles. TRIAD comprises three major components; a computer/linkage/peripheral complex, an out-the-window CIG visual display system and a Bell 206 Helicopter, each integrated together to demonstrate the feasability of embedded simulation for pilot training while maintaining certification on the aircraft configuration. The total system is described and includes the technical approach, an assessment of achieved performance, cost summary and suitability for training applications. A description of the aircraft modifications is presented, detailing how they are achieved without compromising aircraft performance, reliability, or availability. The problems solved and lessons learned during this program are discussed together with an outline of future goals aimed at complete system simulation with minimum aircraft hardware adaptation.

INTRODUCTION

The purpose of this study was to investigate a means of satisfying the training needs of Offshore Logistics, a multi-type helicopter user and operator. In an environment where costs and the risks to train in the actual aircraft have increased significantly, operators have utilized a variety of devices to enhance their training and safety programs in a cost effective way. High technology six-axis simulators have provided realistic flight training but are very expensive and are not conveniently accessible to some segments of the aviation industry. This is especially true where several aircraft types are operated by one organization with the cost of purchasing several simulators being prohibitive.

Embedded simulation is the concept of using the real vehicle that, when stimulated in an appropriate manner, provides the illusion of being operated in the real world environment providing the operator or pilot corresponding perceptive stimulus, and hence, training at reduced capital outlay.

Offshore Logistics, as well as being a major helicopter operator, also supports, maintains and modifies helicopters of all types and has the experience and expertise to design and implement interface adaptations that are necessary to artificially stimulate instruments and controls in a real aircraft cockpit. Rediffusion Simulation, for more than thirty years, has been manufacturing advanced flight simulators, utilizing real aircraft hardware that has been specifically adapted for use in a ground borne simulator.

TRIAD is a prototype simulation complex that is the result of the combined efforts of Rediffusion Simulation and Offshore Logistics to produce a low cost training system which incorporates the sophistication of large simulators with realistic flight and visual cues. The helicopter is an ideal candidate to investigate embedded simulation concepts in that it is of relatively small size, contains simple aircraft systems and is a device that current flight simulators do not address. Helicopters are more difficult to learn to fly than fixed wing aircraft and it is believed that embedded simulation offers a safe and inexpensive approach to recurrent and abinitio training.

TRIAD comprises three major components; a computer/linkage/peripheral complex, an out-the-window CIG Visual Display System and a Bell 206B Helicopter. Figure 1 shows the interior of the Bell 206 cockpit when configured for simulation. The portable instructor control unit, shown on the left, employs a touch sensitive plasma display providing both input and output control, and the out-the-window scene is generated by the NOVOVIEW SP3T CIG Visual system employing back screen projection display techniques.

The use of real aircraft systems in a non-real environment demands special consideration. In particular, the effect of induced vibration on the engine and transmission when in a static condition and its influence on operating life is of major concern. Because of this it was decided not to place TRIAD on a vibrating platform, but rather investigate other ways of providing the illusion of vibration, a necessary part of any helicopter simulation.

OBJECTIVES

The primary objective is to be able to convert a certified operational helicopter into a full high fidelity flight simulator while maintaining the current aircraft airworthiness certification.

Prove "Embedded Simulation" Concept

Prove that embedded simulation has a practical application in providing training capability in a cost effective manner by interfacing real aircraft hardware to a simulation computing complex.

Flight. Employ a high fidelity generic helicopter flight simulation model with some adjustments to approximate the Bell 206B performance characteristics. Verification data will be obtained from limited flight test activity on a Bell 206B aircraft.

Flight Controls. Install positional potentiometers on the throttle, collective, cyclic and anti-torque pedals to obtain instantaneous pilot control movements.

Engines and Rotor. Employ a representative model of the Allison 250-C20 engine and rotor to provide approximate Bell 206B installed performance.

Electrical System. Provide electrical power, from an external source, to the aircraft buses simulating the aircraft generator, battery and 400 Hz converter characteristics.

Hydraulic System. Provide hydraulic power to the aircraft from an external source while interacting appropriately with engine hydraulic pump drive characteristics. With "boost" on, provide the pilot with the same control "feel" as that experienced during flight in the real aircraft.

Navigation. Interact appropriately with NAV selections in the cockpit (VOR, ILS, ADF) for selected real world GCA facilities.

Simulation Equipment. Employ proven software and hardware simulation technology. Use modular hardware interface systems to permit future expansion with minimal redundancy. Use an available, current state of the art CIG visual system, interfaced to the aircraft fuselage for maximum field-of-view and have the flexibility to adapt to different aircraft types.

Total Simulation System Validation.

Determine system viability by monitoring pilot performance, reaction, comment and acceptability of the embedded simulation configured aircraft as a training device.

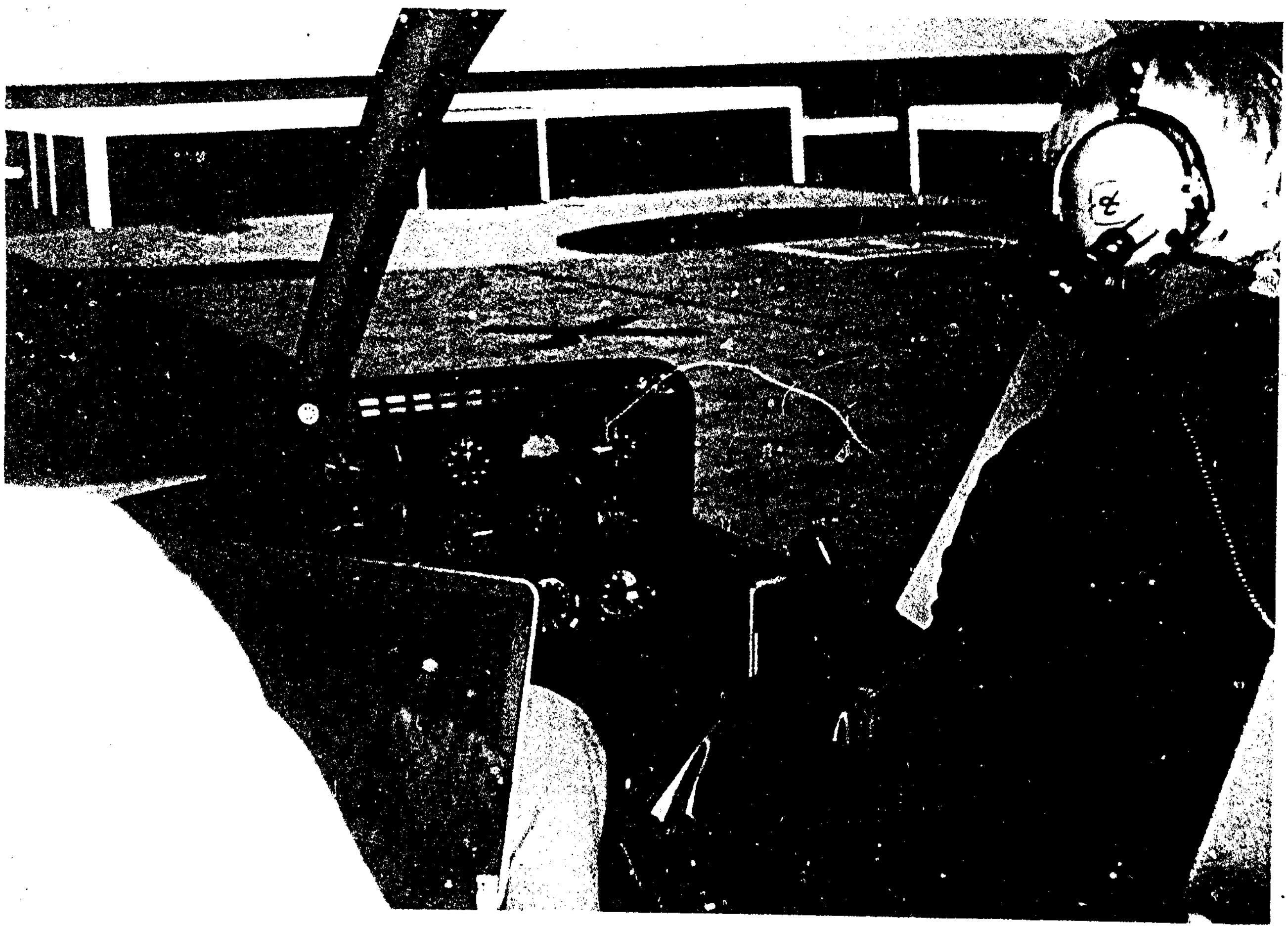


FIGURE 1 TRIAD FROM A PILOTS POINT OF VIEW

Additional Objectives

CIG Visual Display Techniques. Investigate optimum field-of-view/window placement, real image vs virtual collimated image presentation in relation to pilot eye height judgement (recognizing that the display system must be readily adaptable to any helicopter window/fuselage configuration).

Sound/Vibration. Investigate the effectiveness of powerful sound stimulus as a means of introducing realism and low amplitude vibration corresponding to that induced by the transmission and rotor dynamics.

Simulation/Aircraft Interface. Develop an interface strategy that provides for rapid coupling while retaining complete aircraft integrity and safety. Adapting aircraft for full simulation use and return to operation should not exceed two hours.

EQUIPMENT

Summary

Figure 2 shows the layout of the helicopter, the visual display, and the sound system in a room measuring 60 feet long by 41 feet wide. The simulation computing complex and CIG image generator are located in an adjacent room measuring 20 feet by 20 feet. The display screens were oriented to the pilot side and provide a 48 degree vertical by 108 degree horizontal field of view. Figure 3 shows the display screens in relation to the helicopter fuselage.

Figure 5 shows the total TRIAD simulation system and the major lines of communication between system units.

Simulator Computing Complex. The TRIAD simulation computing complex comprises current state of the art equipment and software designed and developed for modern day simulators operated by the major airlines throughout the world.

The major simulator computing complex units are:

General Purpose Computer. SEL 32/2750 by Gould Inc., S.E.L. Computer System Division.

Linkage Interface Type 1406 by Rediffusion Simulation Limited, England

Sound/Vibration System By Labute Professional Sound.

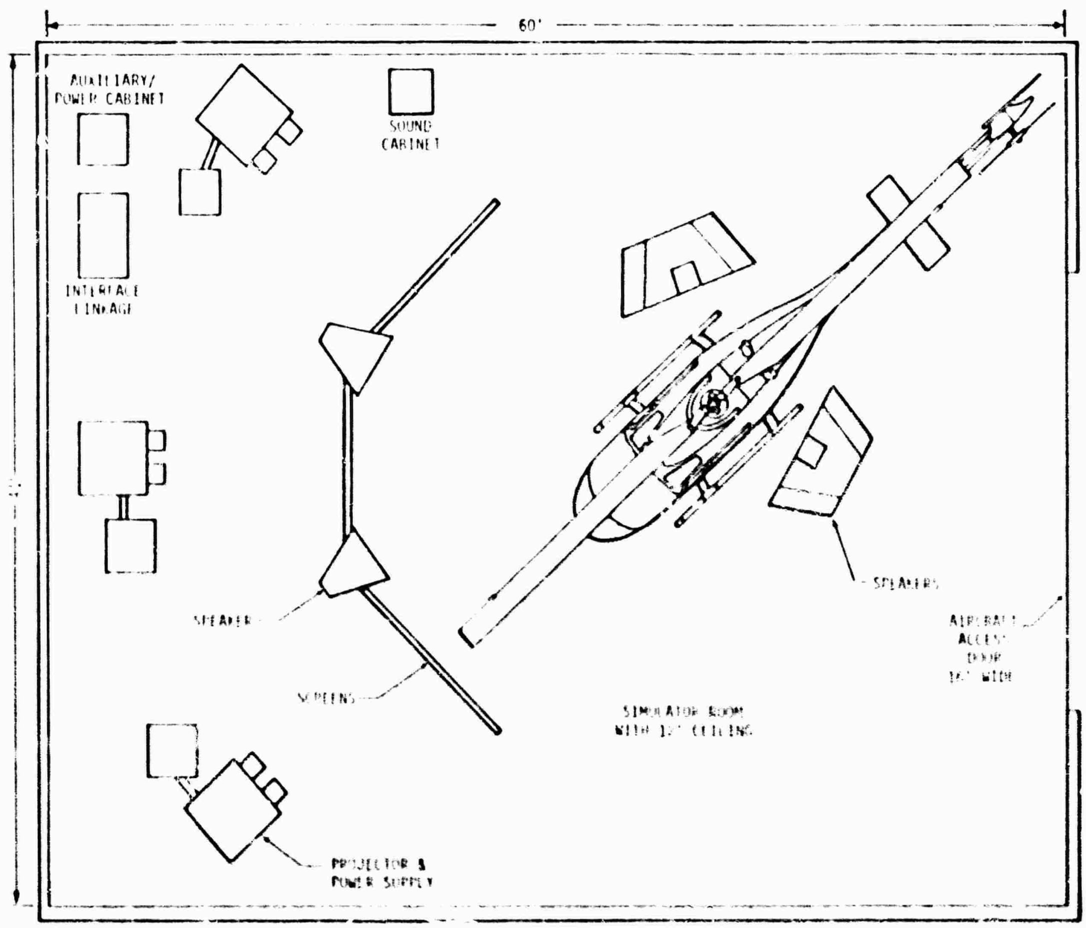


FIGURE 2 TRIAD FLOOR LAYOUT

CIG Visual System. The NOVOVIEW SP3T Day/Dusk/Night Visual System, by Rediffusion Simulation Inc. was chosen for the simulator, not only because it is a day light sytem, but also because it provides textured surface effects. Helicopter pilot controlability depends to a large extent upon the pilots ability to observe small aircraft movements relative to the ground. Textured surfaces will greatly enhance the perceptability of these small movements.

Bell 206B. The Bell 206B (Jet Ranger) is a single engine, land based, utility-type helicopter with a standard configuration that provides for one pilot and four passengers. The main rotor is a two-bladed, semi-rigid, see-saw type employing preconing and underslinging to ensure smooth operation. The helicopter is powered by a model 250-C20 shaft turbine engine, manufactured by Allison Division of General Motors Corporation. A typical instrument panel has fewer than twenty indicators and is VFR equipped with single VOR and COMM capability.

The helicopter configuration used for TRIAD however, is IFR equipped with Dual Nav and Single ADF by King Avionics, an Air Data Computer System by Intercontinental Dynamics Corporation, a Remote Attitude Indicator by Jet Electronics and Technology, Inc., and a full complement of electronic driven engine instruments by Instrument Specialities Co., Inc.

Figure 4 shows the TRIAD instrument panel layout. A complete list of instruments and indicators are shown in the Table, Figure 6.

All the instruments are electronically driven with the exception of the Turn and Slip Indicator. This aircraft instrument is replaced by an electronically driven simulated instrument when the helicopter is configured for training.

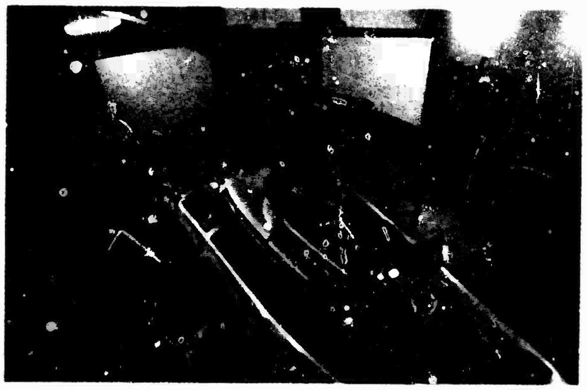


FIGURE 3 TRIAD DISPLAY SCREEN

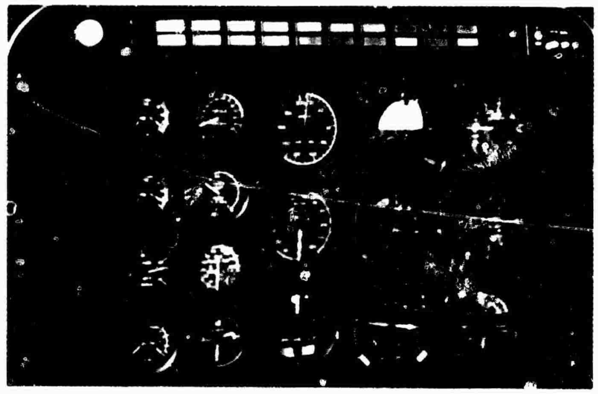


FIGURE 4 TRIAD INSTRUMENT PANEL

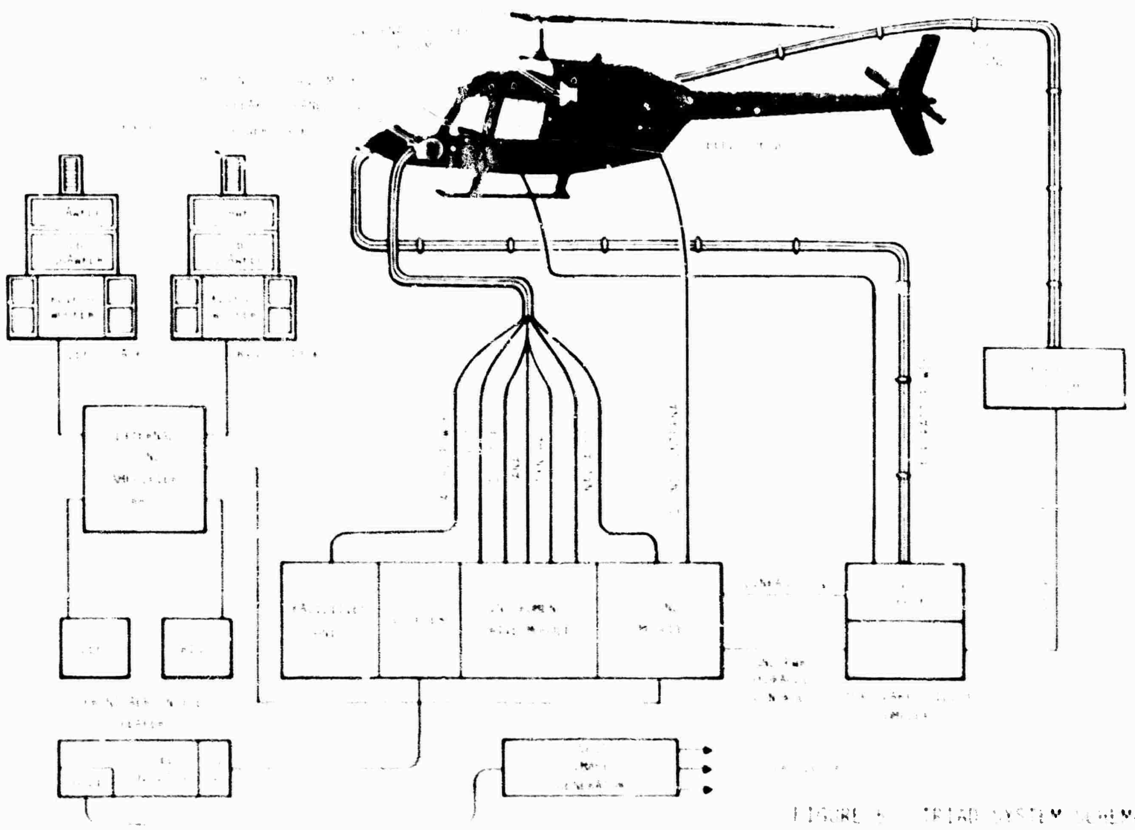


FIGURE 5 TRIAD SYSTEM SCHEMATIC

INSTRUMENT	MANUFACTURER	SIMULATION FUNCTION	REQUIRED INTERFACE	COMMENT
Remote Attitude Indicator RAI 303A	JET	Pitch and Roll Attitude	2 Synchro Drive Channels	
Vertical Gyro VG 208	JET	Drives Marker Flag	Aircraft Wiring Only	
Airspeed Indicator 38610-004	IDC	Airspeed	1 Analogue Output ±10 Volt dc	
Altimiter 15790-202	IDC	Baro Altitude	Dual Synchrodrives	
Vertical Speed 180138-950	IDC	Rate of Climb/Descent	None	Part of ADC System
Air Data Computer 38620-001	IDC	None	None	
Standby Altimeter 31400	IDC	None	None	Not Simulated
Standby Airspeed 36950	IDC	None	None	Not Simulated
Turn and Slip Indicator	---	Turn Rate and Sideforce	2 Analogue Outputs ±10 Volt dc	Simulated Instrument
Radar Altimiter KNI 416	KING	Height Above Ground	1 Analogue Output 0 to 30 Volt Amp Module	
Horizontal Situation Indicator (HSI) KNI 525A	KING	Heading, CDI, Glideslope Localizer Warning Flag	Compass Drive Card 0-200 m volt, 5±100 m volt Analogue outputs Discrete Output	Current Source Drive
Radio Magnetic Indicator KNI 582	KING	Heading VOR Bearing ADF Bearing	Slave From HSI 16 bit Serial Data Sin/Cos Analogue Output	
RNAV Receiver KNS 81	KING	DME Select NAV Selected Course	NAV Selected Course/ Frequency Board	
NAV/Comm Module KX 165	KING	None	None	Not Simulated
Comm Module KY 196	KING	None	None	Not Simulated
Audio Panel KMA 244	KING	Audio Channel Select. Ident Keying	NAV & Radio Aids Boards	M Beacons X-Talk & Indicators
Directional Gyro KG 102A	KING	For HSI	Aircraft Wiring Only	
DME Receiver KR 63	KING	For DME	Aircraft Wiring Only	
DME Indicator KDI 572	KING	DME Ind	DME Serial Data (40 Bit Format)	
Automatic Direction Finder KR 87	KING	Selected ADF Station		Instructor Input
Marker Beacon Receiver KMR 675	KING	Marker Lamps	3 Relays	
Dual Tachometer	INSCO	Rotor & Turbine Speed	2 Tacho Drive Boards	
N1 (Gas Producer) Tachometer	INSCO	N1 Speed	1 Tacho Drive Board	
Fuel Quantity 5707-3007	INSCO	Fuel Qty	1 Analogue Output ±10 Volt. dc	
Fuel Pressur/Load 9016-3020	INSCO	Fuel Press Electric Load	2 Analogue Outputs 1 OP Amplifier	
Engine Oil Temp/Press 9036-3023	INSCO	Engine Oil Temp/Press	1 Analogue Output Digital To Resistance Card	
Transmission Oil Temp/Press 9036-3024	INSCO	Transmission Oil Temp/Press	1 Analogue Output Digital To Resistance Card	
Torque Indicator 4344-3048	INSCO	% Torque	1 Analogue Output 5 + 0 to 100 m volt	
Turbine Outlet Temp 5021-3001	INSCO	TOT Deg. C.	1 Analogue Output 0 to 47 m volt	

FIGURE 6 TRIAD INSTRUMENTS

Aircraft Modification. In order to preserve instrument certification, none of the aircraft instruments are modified, adjusted or altered in any way. All interfacing is accomplished via changes to system wiring. The aircraft wiring is modified so that all pertinent signals are routed through a "breakout panel" conveniently located to the lower left of the central console (near the co-pilots feet). Figures 7 and 8 show the breakout panel, its location and the cabling both inside and outside the aircraft. A hole, made specifically to accommodate the interface cables, was cut in the helicopter plexiglass windshield. A plexiglass cover has been made that completely covers and seals the hole when the helicopter is configured for flight.

Three examples of system wiring modification, namely the Fuel Quantity Gauge, the Navigation System, and Aircraft Power are described below to show the interface design concept:

Fuel Quantity Gauge. Figure 9 shows three schematics of the fuel quantity gauge. View A shows the unmodified aircraft system. View B shows the modified system when configured for flight. The gauge drive signal is routed through the breakout panel on its way to the gauge but in reality has no effect on system operation. View C shows the modified system when configured for simulation. In this case, the drive signal (0 to 5 volt DC analogue out) originates in the simulation computing complex interface and is routed through the breakout panel to the gauge.

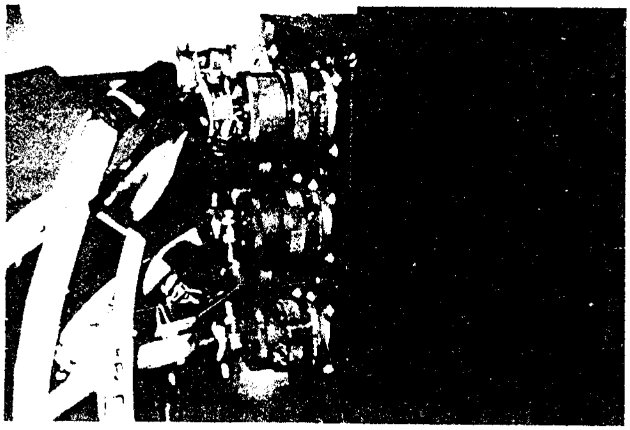


FIGURE 7 BREAKOUT PANEL

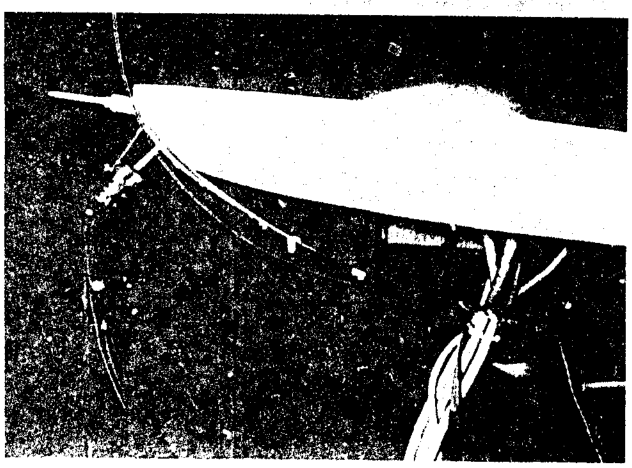
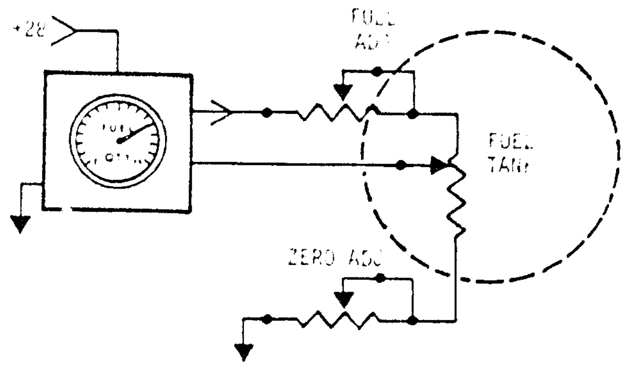
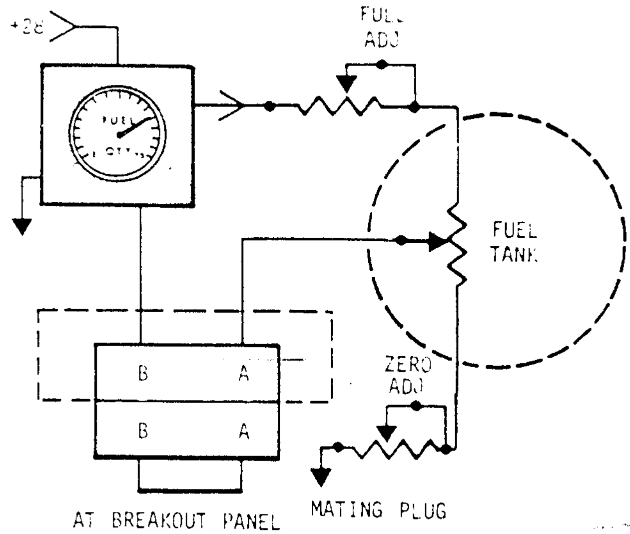


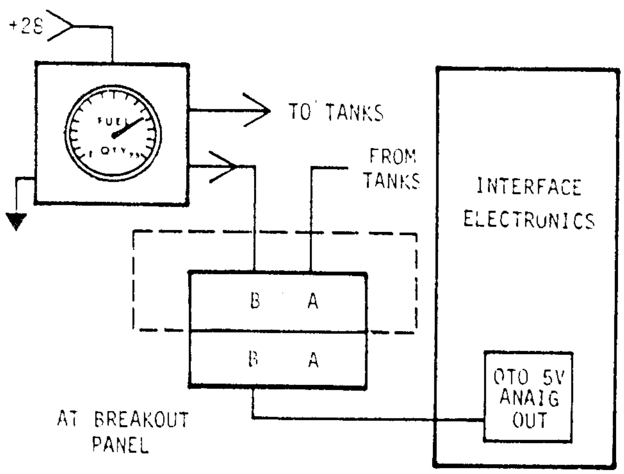
FIGURE 8 INTERFACE CABLING



A. UNMODIFIED AIRCRAFT



B. "FLIGHTWORTHY" 206 - FUEL QUANTITY SYSTEM



C. SIMULATOR FUEL QUANTITY SYSTEM

FIGURE 9 FUEL QUANTITY GAUGE SCHEMATIC

Navigation System. Figure 10 shows the Navigation System when configured for simulation. The figure shows signals that simply route through the breakout panel, some that originate in the simulation computing complex and some that route data back into the simulation computing complex. The column to the left of the figure represents the simulation computing complex interface electronics, the breakout panel is shown centrally and the aircraft equipment shown to the right.

The Horizontal Situation Indicator (HSI) is the primary navigation instrument and independantly displays heading, course and glideslope deviation and various warning flags. Each of these indicators have a separate drive signal as shown in the figure. The HSI heading repeater signal to the Radio Magnetic Indicator (RMI) is not broken by the breakout panel and is used as the servo feedback to the HSI heading stepper motor drive. In the flight configuration the complete drive and servo control is done by the Remote Directional Gyro KG 102A. RMI heading is slaved to the HSI heading.

The Automatic Direction Finder (ADF) bearing is driven from the simulation computing complex interface as three analogue outputs in the form of dc sin, dc cosine and reference values. The Vertical Omni-directional Radio (VOR) indicator is driven by 16 bit serial data, routed through the breakout panel and generated by a special card in the simulation computing complex interface. The Marker Lamps are driven by 6 volt power relays that are triggered by discrete outputs from the simulation computing complex interface.

The Distance Measuring Equipment (DME) is driven from the simulation computing complex interface by a special card that emulates the aircraft KR63 DME Receiver and provides the digital 40 bit format data necessary to drive the indicator.

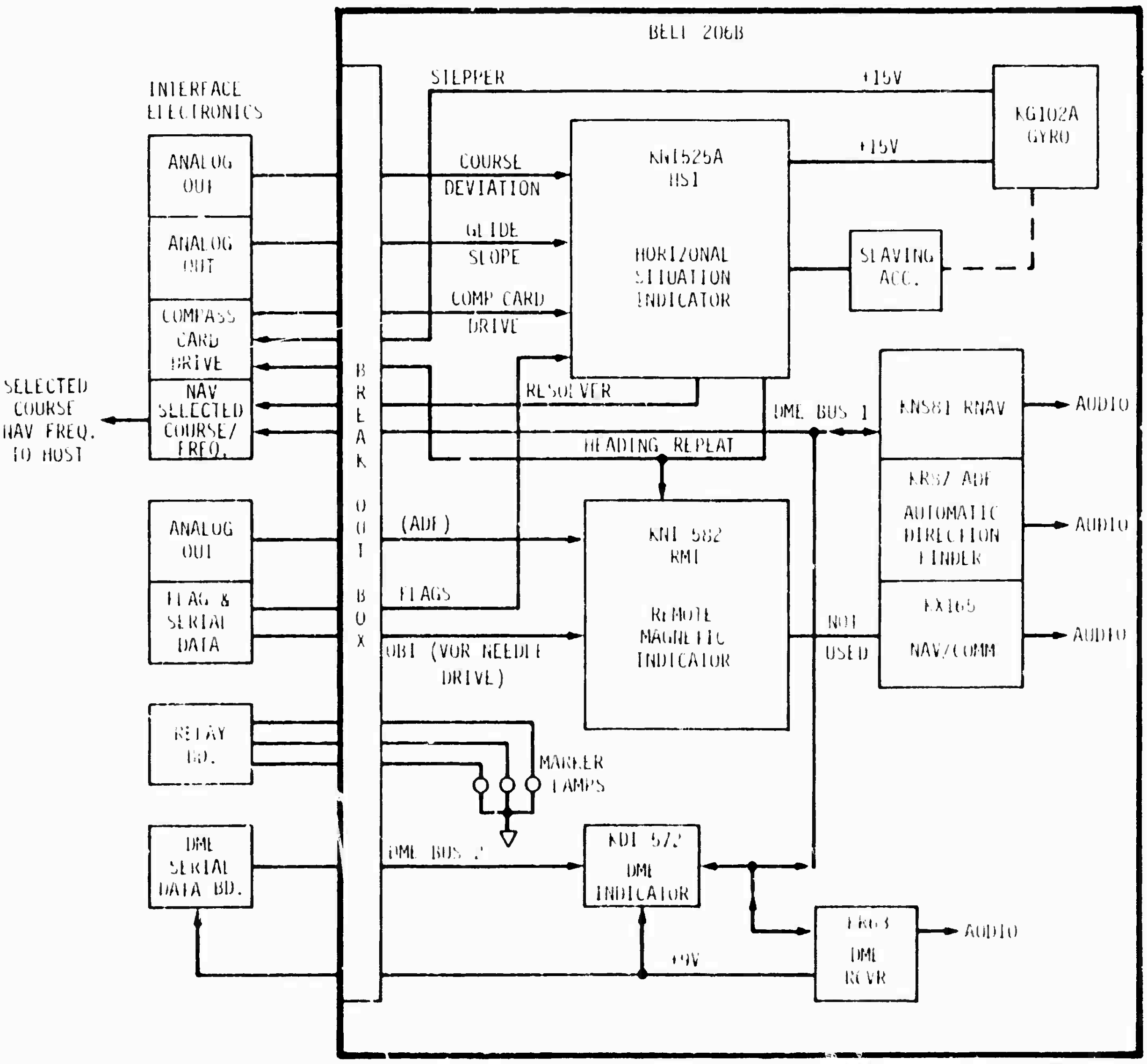


FIGURE 10 NAVIGATION SYSTEM

Aircraft Power. The aircraft power for all systems is derived from a +28 Volt DC Power Bus. Figure 11 shows the simulation schematic for the 28 volt power system. The simulation computing complex interrogates the aircraft Battery Switch and Ground Power Switch, and when either are sensed as ON the power relay in the interface is activated, which in turn, activates the external power relay in the aircraft. All aircraft circuit breakers are routed through the breakout panel so that when in the simulation mode, the condition of the circuit breakers (ON or OFF) is known to the simulation complex. The simulation software determines the corresponding condition of the system/indicator and produces appropriate drive output to the aircraft.

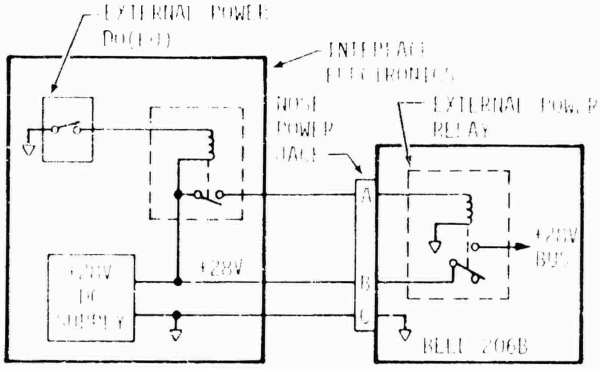


FIGURE 11 AIRCRAFT POWER SCHEMATIC

Flight Control Position. Five positional potentiometers have been installed at appropriate positions on the pilot control linkages to provide positional information to the simulation computing complex. The monitored flight controls are:

(a) Fore and Aft Cyclic

(b) Left and Right Cyclic

(c) Throttle

(d) Collective

(e) Anti-Torque Pedals

The following Figures show the installation of the flight control potentiometers:

Figure 12	Anti-Torque Pedals
Figure 13	Cyclic
Figure 14	Collective
Figure 15	Throttle

These positional potentiometers are electrically isolated from the aircraft since they have no function in the flight configuration. Resolution provided by the potentiometers is as follows:

Control	Range of Travel	Resolution
Collective	35 degrees	2 arc mins
Cyclic (both)	30 degrees	1.7 arc mins
Anti-Torque	180 degrees	10 arc mins
Throttle	6 centimeters	0.1%

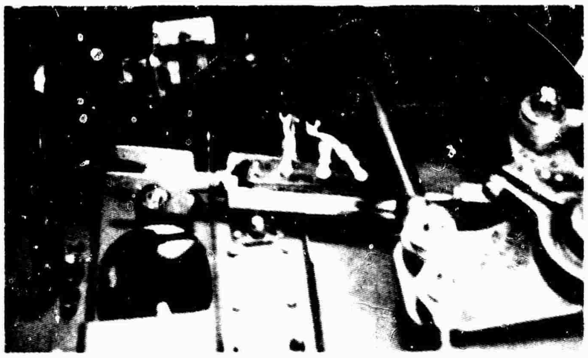


FIGURE 12 ANTI-TORQUE

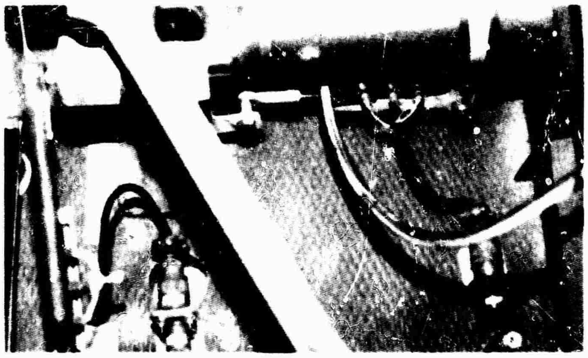


FIGURE 13 COLLECTIVE

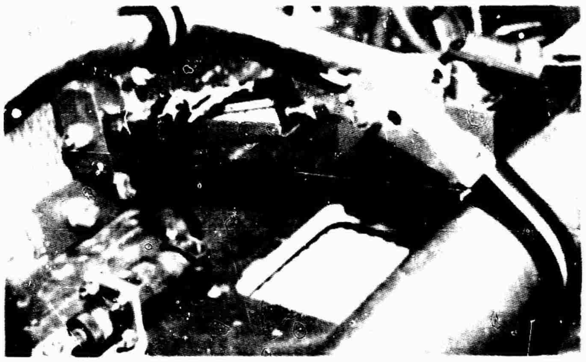


FIGURE 14 CYCLIC

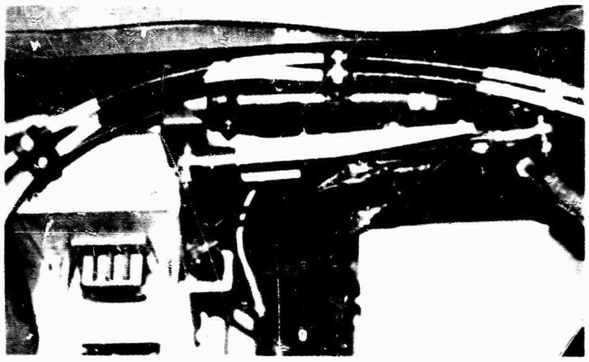


FIGURE 15 THROTTLE

Safety. Special safeguards are required when utilizing real aircraft equipment for simulation purposes. Each breakout panel connection is uniquely keyed so that there is no possibility of incorrect connections causing inappropriate electrical power routing. Systems that should not be operated when the aircraft is configured for simulation, i.e., pitot heat, engine starter and igniters, are disabled by appropriate circuit design of the breakout panel connections.

Careful design is incorporated in the simulation computing complex interface to ensure the aircraft units will not be subject to over voltage conditions. Power is not applied to the aircraft until the simulation computer is active. Additionally the engine starter circuit is routed through all eight breakout panel aircraft configuration connections so that the aircraft cannot be operated unless every connection is correctly in place.

An Emergency Stop switch is located near the left hand seat bulkhead when in the simulation configuration. The stop switch removes all electrical and hydraulic power to the aircraft when actioned.

Hydraulic System. Figure 16 shows the helicopter hydraulic circuit when configured for simulation. An auxiliary power unit provides power at the same pressure and flow as that experienced in the real aircraft. The hydraulic connection is made at the aircraft "quick disconnect" couplings (units 10 in the figure). The operation of the auxiliary power unit motor starter and solonoid valve are controlled from the simulation computer complex to simulate the effects of engine speed on available hydraulic pressure.

The aircraft servo actuators provide movement to the aircraft control devices and remove feedback forces to the pilots hands. By powering the aircraft hydraulic system when in the simulation configuration, the "feel" experienced by the trainee pilot will be representative of that of the real aircraft in flight.

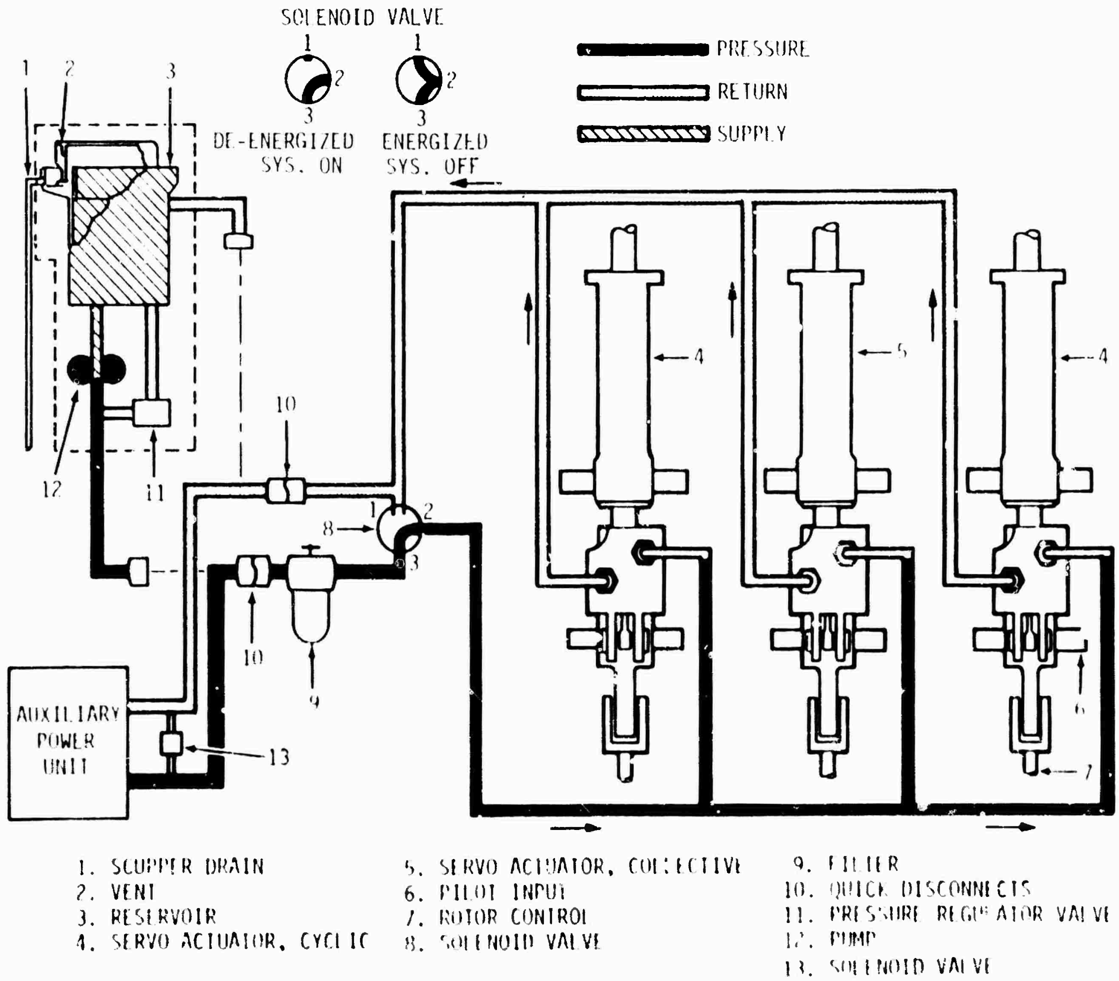


FIGURE 16 TRAIP HYDRAULIC SYSTEM SCHEMATIC

Simulator Computing Complex

Computer and Peripherals. The TRIAD computational sytem uses the SYSTEMS 32/2750 General Purpose Computer and includes a disc based operating system suitable for simulation applications.

The computer complex schematic is shown in Figure 17 and consists of one 80 mega byte, moving head disc drive; one magnetic tape unit for development support and data backup; one 175 CPS printer; two CRT editor terminals, two CRT Digital Readout Unit & Interactive Displays (DRUID); and one CRT Operator's Console (OPCON). The OPCON replaces the mechanical keyboard and greatly enhances operation and maintenance of the computer complex. The DRUID enables direct memory access for on-line alteration or debug of simulator software systems.

The computer configuration for TRIAD consists of a single slot CPU, 512KB interleveled error correcting memory, an MTU processor, a disc processor, two I/O devices (High Speed Device Interface) capable of 3.2 megabytes bi-directional data transfer, and an Input/Output Processor which handles multiplexing between the main CPU data bus and a multipurpose bus used for external devices such as the OPCON. The real time clock signal is provided by the linkage and all hardware/software is slaved to this one timer to provide exact syncronization of all simulated systems.

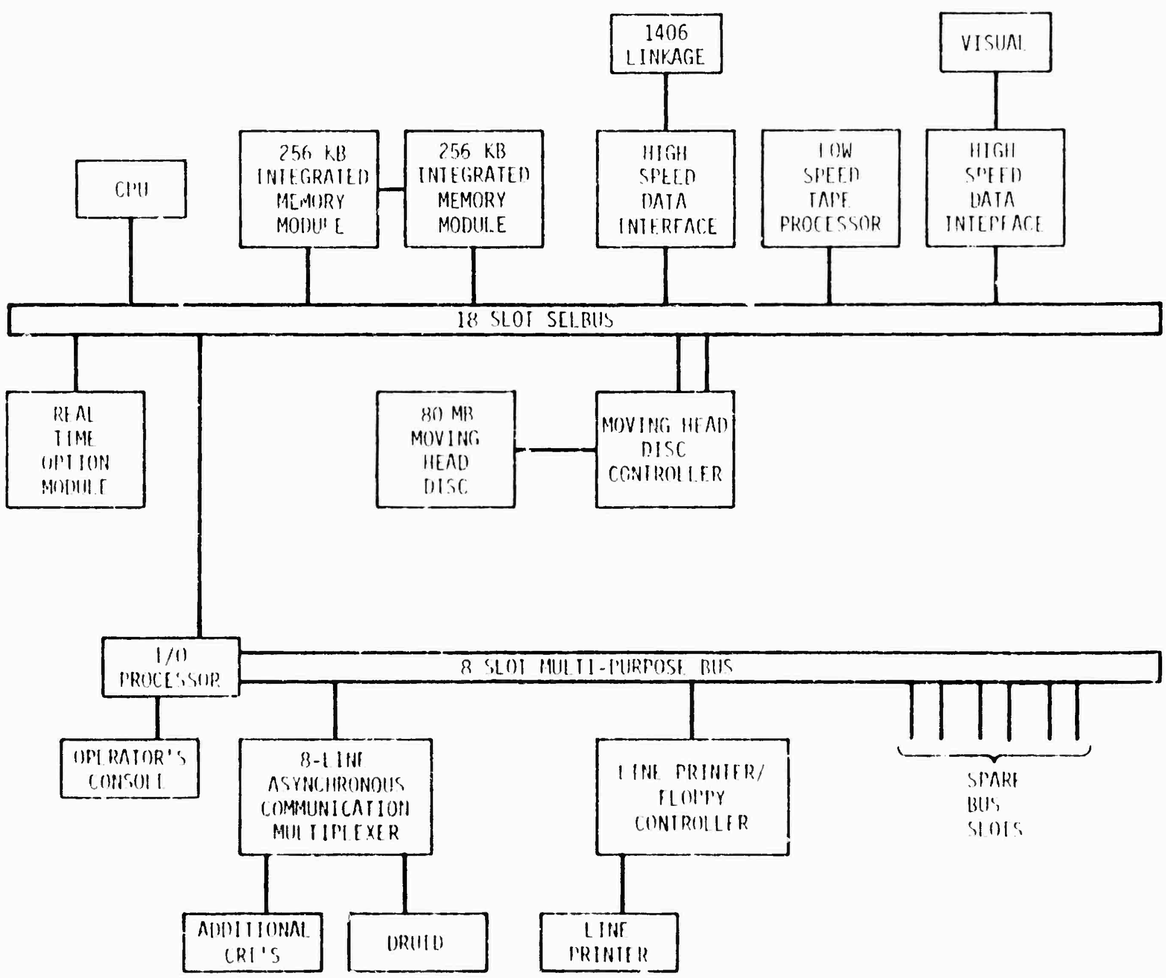


FIGURE 17 SEL 32/27 COMPUTER COMPLEX

Computer Software. The software used for TRIAD can be separated into three major sections: 1) Operating Systems; 2) Simulation modules and their executives; 3) Simulator support programs including maintenance, test and diagnostics. A maximum iteration rate of 30 Hz is used to ensure as high a fidelity as possible in the performance areas such as flight dynamics, flight control interface and visual transfer. Other simulator systems modules are installed at lower rates but in all cases at a rate which provides adequate time for accurate duplication of that system. Figure 18 shows the family tree of software units that make up TRIAD computer software.

Operating System. The operating system software is a Rediffusion modified version of the SYSTEMS MPX-32 Disc Operating System. These modifications include software which shorten module computation time by placing math subroutines in memory to be called as needed, and enables real time memory access through DRUID. The math subroutines enable rapid calculations of trigonometric functions, integration, interpolation, function generation, etc. thus shortening CPU execution time for simulator modules. DRUID allows memory access through CRT/keyboard manipulation and enables the user to address any location in the simulator module and the state of all CPU registers at each location. Entries can be made in hexidecimal, decimal or character codes. Indexed instructions can be monitored at the exact index register specified by the code. Any changed memory location will remain in that altered state until changed again by DRUID or until a new system is loaded from disc.

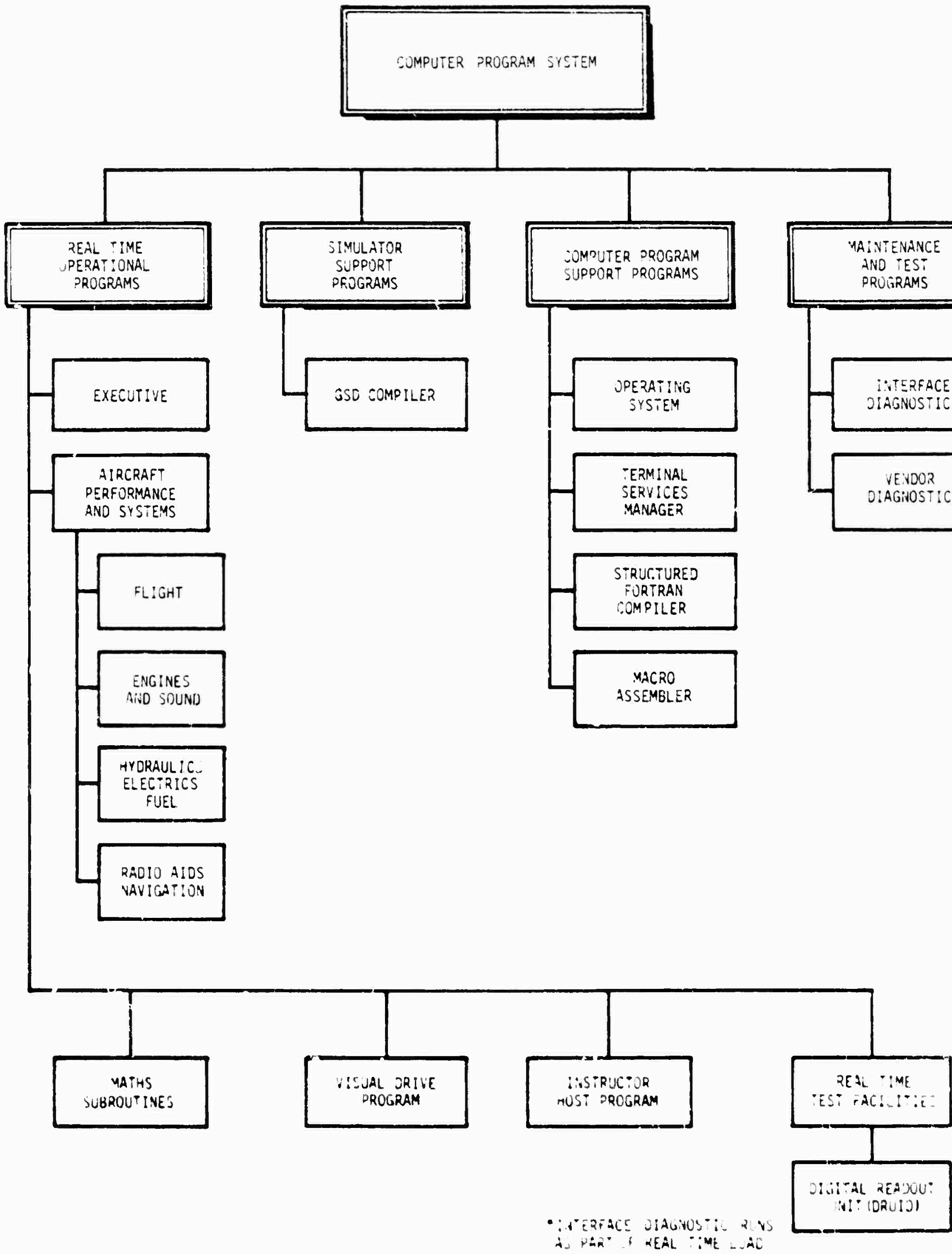


FIGURE 18 TRAID SOFTWARE SYSTEM

Simulation Modules and Their Executives. These programs implement information processing to simulate aircraft performance, on-board sytems peformance, aircraft sound environment, weather and atmosphere, navigation and radio aids systems and instructor functions including accurate depiction of malfunctioning systems as selected by the instructor. The accurate dynamics of systems such as flight, fuel, electrical, engines, sounds, radio navigation, etc., are present in the TRIAD simulator load. The Master Executive module provides the order and time of execution of each sub system module, and maintains priority in the CPU foreground tasks to insure all simulator tasks are accomplished as called. Background tasks (i.e. editing, cataloging, Library Editing, Batch jobs) may be done as desired even in the normal simulator training mode of operation.

Simulator Support Programs The Simulator Support Programs, a few of which were mentioned above, allow the simulator operator to manipulate, edit, modify, assemble, compile and run any program in the simulator computer. New source programs may be added, if desired or existing ones modified to fulfill the needs of the operator. A Ground Station Data (GSD) Compiler and Editor is included to enable programming of virtually any naviqation aid in the world for use by the simulator aircrew for training. 375 stations may be active at any one time, with the maximum number of stations available for call limited only by disc storage area. S.E.L. Level I & II software diagnostics are included as a maintenance aid. The simulator load can not be run while level I or II is being executed as it demands full time use of the CPU, the SELBUS, and any peripherals attached. These diagnostics isolate malfunctions to a major assembly (circuit card) level, thereby minimizing down time with board replacement being acomplished by the user.

The majority of source programs for TRIAD are written in SYSTEMS assembler language to minimize computational time. However, many support and control programs are written in FORTRAN.

Simulator Linkage Interface. TRIAD utilizes an interface system which takes maximum advantage of proven state-of-the-art techniques in electronic component technology, packaging and data transmission. The operational characteristics of the interface are matched to the high speed data transmission capabilities of the SYSTEMS 32 series computer and the almost exclusive use of aircraft instruments throughout the flight deck. The interface is fully integrated with the sound/vibration system and is capable of meeting the high speed response demands of helicopter flight and instrument systems.

Figure 19 shows the disposition of individual modular units comprising the interface system.Key features in the design of the interface include:-

Multiplexed Digital Data Transmission. The primary data bus (PDB) transmits multiplexed digital data in two cables between the simulator computer and the interface cabinets.

Function Boards. Aircraft instrument drive signals are derived from a selection of standard function board channels that removes the need for complex special-to-aircraft type system boards.

Power Supplies. The interface cabinet is equipped with the required power supplies that are fully protected by circuit breakers.

Cockpit Power Supply. In addition to the ac/dc power required for the linkage electronics, an external source of regulated 28 VDC power is necessary for the cockpit environment. A 30 amp power unit is located in a separate cabinet and provides power to both the linkage and cockpit.

Diagnostics. A comprehensive range of interface diagnostics operate on-line, during training. Each interface channel is interrogated at regular intervals and failures are identified on the operator output device. This enables the defective unit to be removed and replaced.

Interface Cabinet Layout

The cabinet layout for TRAID contains five levels of equipment, where each level is 178 mm (7 in) high, as shown in Figure 19.

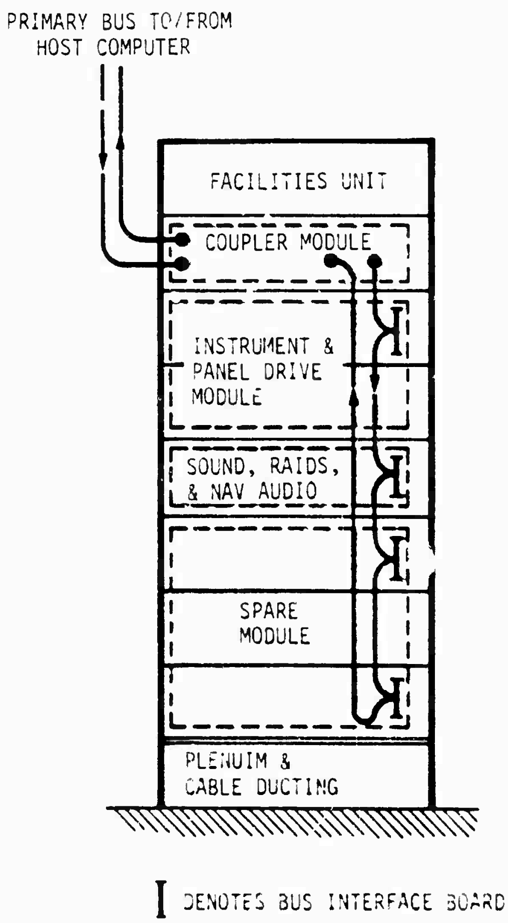


FIGURE 19 INTERFACE CABINET LAYOUT

The top level contains the cabinet facilities unit. The unit distributes the various power lines and services from the power distribution bay to the ac and dc power supplies within each card cage. Smoke and overheat detectors and fan units are also contained within the facilities unit.

The central four levels contain the interface electronics designed to accommodate a range of standard cards capable of driving instruments and indicators normally used in aircraft. The range of cards used for TRIAD are listed below:

Analogue Input	Analogue Output
Discrete Input	Discrete Output
Addressable Relay	Synchro Driver
Servo Amplifier	QUAD Amplifier Card
Power Amplifier	Sound System Cards
Nav. and Radio Aids System Cards.	

These cards are arranged as equipment modules as shown in Figure 19.

Coupler Module. The coupler module, controls all communication between the SYSTEMS 32 host computer and the various modules.

The SYSTEMS 32 computer contains a high speed direct memory access channel known as the high speed data interface (HSDI). This connects to the coupler module via a bi-directional highway known as the primary data bus (PDB). A unidirectional data highway originates at the coupler and loops around the on-board equipment before returning to the coupler. Each of the equipment modules connect to the bus. Messages originating from the coupler module are transmitted around the bus and carry data to and from the various modules.

Panel Drive Module. This module contains the electronics associated with aircraft panels and consists predominantly of discrete inputs boards (monitoring switch positions) and discrete outputs (driving lamps).

Instrument Drive Module. This module contains the electronics associated with aircraft instruments, i.e. synchro drives, servo amplifiers, various ARINC serial transmitters, etc.

Sound and Radio Aids Module. Level 5 of the linkage contains the electronics necessary to generate 206B sounds including environment outside the cockpit. Also in this module are the electronics necessary to drive the navigation instruments.

Sound Simulation

After an extensive analysis of the sounds produced by a 206B helicopter in all modes of operation, the following innovative techniques were employed to surround the pilot with a realistic atmosphere of sound:

Point sources of individual noises were isolated to the origin from which they were generated.

Pressure levels and volume of noise were measured from each source.

Unique sounds (i.e. "blade slap", blade stall, skid slide noise) were isolated and the frequencies of each were identified.

Interior sounds such as boost pumps, fuel valves and generator sounds were recorded and identified.

Blade passing sounds and frequencies were obtained.

To more accurately simulate this aircraft, realistic in flight sound pressure levels are produced to bombard the interior and exterior of the cockpit to stimulate the sense of motion and vibration achieved in actual flight. It was necessary to generate 110-114 dbA in order to penetrate the cockpit shell with enough energy and sound realism to match the 93-98 dbA which normally is present in this aircraft. An auxillary sound cabinet receives software controlled, hardware generated composite audio. This audio is then channelled to its appropriate point source and is amplified to the representative level of energy. Very high efficiency professional sound equipment, including 1/3 active equalizers, frequency crossovers, power amplifiers and speakers, are employed to recreate this envelope. Point source sounds are blended and matched to five speaker locations. The front left, and front right elevated speakers are the origin for the blade swish sound and accompaning blade passing. An aerodynamic hiss is also blended here to provide the air rush noise heard over the canopy during flight. A three speaker group inside the rear of the cockpit centralizes sounds which originate inside the ship. Engine and transmission noises are the primary sounds heard, but also blended into this audio are boost pump and generator noise. Because engine and transmission sounds can be heard outside the cockpit, there are two additional stacks of speakers, with a frequency range of 20-20KHZ, directly on the left and right sides of the cockpit and positioned to penetrate the shell at the same angle as that experienced in the aircraft. Retreating blade sounds are blended into the left outside stack. Blade Slap is created by the advancing blade during rapidly changing aerodynamic conditions or under high blade loads and is reproduced in the right outside stack. All outside speakers are modulated with a 13.15 HZ blade passing frequency and this modulation coupled with a low frequency (Below 30 HZ) noise creates the thump or vibration of a two bladed helicopter. Sounds from engine start, through hover and translational lift to forward, rearward or sideward flight, into cruise and even to engine out autorotation to a landing are accurately reproduced to provide the pilot a realistic environment.

Instructor Control

A flight simulation complex usually incorporates a permanent instructor facility located either inside the simulator cab or offboard in a separate room. Because TRIAD employs a real aircraft fuselage, the instructor may be located at the co-pilot station. A portable instructor facility is required that has the capability to fully control the simulator and provide malfunction conditions and, of course, be easy to use.

Vupoint Portable Display Unit   Vupoint employs a touch sensitive plasma display driven by a National Semiconductor Z80 based microprocessor. The display can present up to twelve lines of 40 characters each per page, and has internal storage capacity of up to 64 pages. Figure 20 shows the Vupoint display unit. The front screen assembly can be detached from the main casing for use on the instructor's knee as shown in Figure 1.

The pages are arranged in a logical sequence and include an index, set-up pages, i.e. weight, CG etc, resets, freezes and system malfunctions.

To select a page, change a parameter, or insert a malfunction, the instructor simply "touches" the appropriate text on the page. Infrared transmitters and receivers located around the edge of the display detect the touched screen position that cause system software to implement the appropriate action.

Visual System

The visual system consists of three major components: The computer generated image system, the calligraphic projection system and the backscreen assembly.

Computer Generated Image System   The image generator is a NOVOVIEW SP3T Day/Dusk/Night image generation (IG) system. It employs a TI-980B based computer processor and a frame rate of 46 HZ during daylight mode and 30 HZ during dusk and night operation. The IG is capable of up to four channels, with three installed and operational on TRIAD. The IG is interfaced to the simulator computer via a high speed DMA interface. Control and pilot eye coordinate and attitude data are transferred to the IG each simulator computer frame.

SP3T is a follow-on product of the SP3 FAA Phase III certified visual system, and provides all the features of SP3 plus texture. Various textural patterns can be applied to surfaces in the scene to give the appearance of clouds, sea waves, grass, concrete, forest, etc. This image generation system is incorporated in TRIAD because it is believed that the texture feature will provide the helicopter trainee pilot the precise visual information he needs to successfully fly and land a helicopter.

Calligraphic Projection System   The Rediffusion Calligraphic Projector can display both calligraphic lightpoints and raster generated surface during a single IG frame. Three projectors are used for TRIAD and each consist of a head unit, a power unit and a remote control unit.

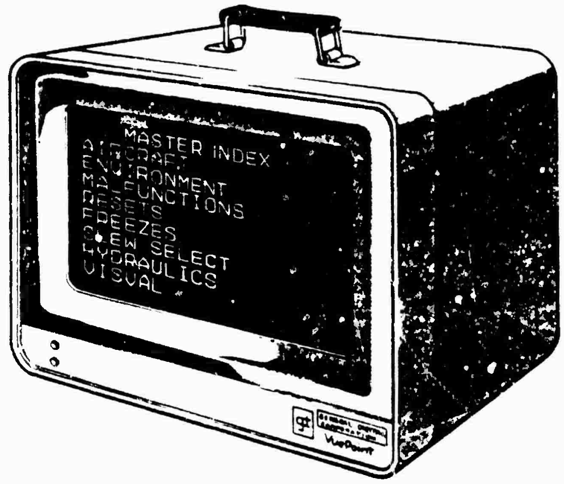


FIGURE 20 VUPOINT CONTROL UNIT

Projector Head Unit.   The head unit is an assembly incorporating three projection tube assemblies (red, green and blue) and their associated scanning systems, the EHT generator and video processing equipment. The tube assemblies are housed within a rigid light-weight aluminum casing. Each projector head unit is supported on a frame and positioned relative to the corresponding backscreen for correct geometric alignment.

Projector Power Unit.   The power unit is a floor standing cabinet containing the deflection power supply, ±24 volt power supplies, tube heater supplies and video and HT power supplies.

Projector Remote Control Unit.   The remote control unit enables the projector to be callibrated from the pilot viewing position inside the helicopter by a single operator.

Backscreen Assembly   Each projector is mounted behind the display screen assembly completely out of the pilot's view. The backscreen assembly is comprised of a framework supporting three eight foot high by six foot wide flat translucent panels. The panel material has an optical diffusing coating for high resolution images.

Each panel is oriented such that the pilot views screen at a perpendicular angle to present a continuous horizontal image. The size of this image is 48^{o} vertically and 108^{o} horizontally.

Data Bases   Several data bases are used for TRIAD, ranging from a gulf oil rig, a ship landing platform, to a standard airfield. Obstacles are located at critical locations in the data bases to ensure pilot skills are exercised to their maximum during TRAID pilot assessment.

RESULTS

The objective of adapting a certified helicopter for use as a full high fidelity simulator to be used for pilot training was achieved.

"Embedded Simulation" Concept

All of the objectives to prove the "Embedded Simulation" concept were achieved. The generic helicopter flight simulation model was successfully modified to approximate the Bell 206B performance characteristics. All of the aircraft systems were utilized in conjunction with the simulation complex and the out-the-window CIG Visual Display System.

Total Simulation System Validation

Four visual models were used to evaluate sytem capability and pilot performance. These models were:

1) Montgomery County Airport, Conroe, Texas
2) Perry Class Frigate Underway
3) Offshore Oil Drilling Platform
4) Nuremburg, Germany, Municipal Airport.

Model 1 provided the capability to demonstrate hovering, air taxiing, pedal turns, translation to forward flight, climbs, decents, approach to landing and landings. Visual cues and system response were adequate to provide a training capability for novice pilots as well as proficiency training for the experienced pilot.

Model 2 provided a helipad on a frigate underway at sea. Cues such as a rotating radar antenna, bow wave and wake, and moving seastate were provided allowing the pilot to practice normally difficult landings.

Model 3 demonstrated the realism of operating on an offshore oil drilling platform providing the capability to enhance pilots training for all levels of qualification.

Model 4 provided a full ILS approach capability as well as the normal runway and traffic pattern functions. Category II approaches to minimums were utilized as well as simulated emergencies such as transmission failures and chip lights. The full range of autorotation practice as a result of engine failures was also demonstrated. Hovering, straight in, and 180^{o} autorotations to full stop landings were accomplished with a degree of realism that provided the touchdown response appropriate to the degree of impact.

Computer Image Generated Visual Display

The wide screen with rear projection provided a real non-collimated image with a 108 degree horizontal and 48 degree vertical field-of-view. This view is continuous and can be viewed from any position in the cockpit without losing or having the visual fade. The texturing of the visual display provided the critical cues for height, closure and acceleration that are mandatory for low level helicopter flying. The realism lines on the concrete runways and taxiways, the tire-marks on the runways, the mottled ocean surface, grass and tree tops and the overcasts and cloud surfaces are all authentic and lend to the realism of the simulation.

Sound and Vibration

The sound system provided a high degree of realism by including actual engine, transmission, rotor, slipstream and touchdown vibrations of the operating aircraft to the pilot.

Simulation/Aircraft Interface

The goal of adapting a certified helicopter for simulation use and return to full operation in two hours or less was more than met. It was demonstrated that the Bell 206B could be placed in operation as a simulator in 44 minutes and returned to full flight operation in 15 minutes by two people. Figure 21 show the TRIAD helicopter during its proving flight.

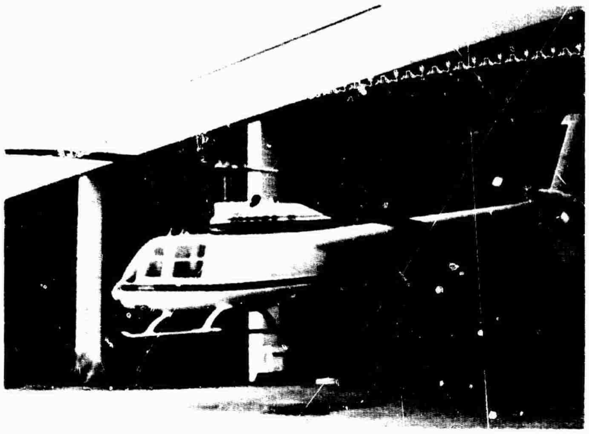


FIGURE 21 TRIAD PROVING FLIGHT

General Results/Comments

The TRIAD concept was demonstrated as a production prototype for three months prior to this paper submission. The objective was to expose the concept to a broad range of aviation related personnel and to gather comments on the prototype system.

All participants in the demonstrations were advised of the prototype status and the various areas which would be either improved or modified in the production systems. Each participant was encouraged to critically evaluate the system on the basis of both inputs. The production time scale would allow for inclusion of almost any modification that surfaced consistently as a result of these demonstrations.

Upon termination of the demonstration phase, the only consistent result was that the system functioned remarkably well as a training device. Pilot acceptability of the flight characteristics, as compared to a Bell 206 aircraft, was extremely positive.

The absence of a motion base on the system was emphasized in each pre-brief to participants as being one of the major departures from conventional simulation devices. Each participant was asked to critically evaluate this particular aspect during the demonstration. The overwhelming concensus was that the absence of motion was not particularly noticed given the apparent motion created by the visual-sound combination. Further, concensus indicated that pilots who had received training on current motion based helicopter simulators were able to achieve a more rapid accommodation to the system and performed low level flight and hover maneuvers with greater ease. The ability to operate effectively at very low altitudes with a TRIAD system may resolve the question of motion versus non-motion in flight simulators.

While the results gained from the demonstration phase are not presumed to be scientific, the overwhelming positive response to the TRIAD sytem would indicate that the approach is valid and that acceptability as a training device is fairly unanimous.

Cost Analysis

For a given visual system, TRIAD will represent a considerably smaller initial investment. For purposes of example only, assume an acquisition cost of approximately $4.5M for TRIAD (to include one software package); $750K for additional TRIAD aircraft interface software packages; and, $6.0M for a conventional simulator. These assumptions achieve a savings of approximately 25 percent for a one aircraft system.

Using the above cost approximations, assume a situation in which five aircraft types can be simulated. The TRIAD system cost would be $4.5M + $750K x 4 = $7.5M. The conventional simulator would cost $6.0M x 5 = $30.0M. These assumptions achieve a savings of approximately 75 percent for a five aircraft system.

TRIAD will represent the same, or better, results in simulator versus aircraft training trade-offs when compared to a conventional simulator.

A study by Orlansky and String (1979) gives considerable insight in the various areas of simulation cost analysis that should be considered.

FUTURE DEVELOPMENTS

The main objective of TRIAD was to prove that Embedded Simulation is a concept that has practical application for pilot training. The most expedient technical approach was employed on the basis that a more general approach would be implemented should TRIAD be successful. The lessons learned during this project lead to the following future developments that will provide a better, more flexible total simulation system.

Pneumatic Instrument Drive System

TRIAD was configured with an Air Data Computer instrument system permitting electrical drive to the Altimeter, Airspeed Indicator and Vertical Speed Indicator. A planned TRIAD development is to apply pneumatic pressure/vacuum directly to the pitot head and static source sensors in a precise manner to drive the air driven instruments to a resolution comparable to that experienced in flight.

Dedicated Simulation Model.

TRIAD employed generic flight, rotor and engine simulation models that were suitably adjusted to provide approximate Bell 206 performance. Future TRIAD products will employ simulation models for the aircraft systems that have been rigorously designed from aircraft manufacturers substantiated data.

Control Loading

Many small helicopters do not employ fully boosted hydraulic control units on all its flight control systems. The anti-torque system on TRIAD, for example, was not boosted and therefore does not provide the aerodynamic feedback forces normally experienced by the pilot.

It is planned to develop a small, highly portable control loading unit that can easily be mounted to any aircraft frame and control linkage, that can readily be calibrated and will provide appropriate force feedback to the pilot under all normal maneuvering conditions.

Visual Display Improvements

The non symmetrical field-of-view proved not to be ideal since helicopter maneuvers usually require equal vision on either side of the cockpit. The helicopter will be positioned with the three display units placed symmetrically about the pilot producing a 48 degree vertical by 108 degree horizontal field-of-view. It is also planned to assess a four screen 144 degree horizontal field-of-view display configuration.

Vibration

The pilot and copilot seats on the Bell 206 fit over a spacious part of the helicopter fuselage containing the flight control linkages. To augment the sound/vibration system, it is planned to design a "seat vibrator" that can be located in this space under each seat. It is important that vibration is not induced in the aircraft framework, engine or transmission and therefore a seat vibrator employing seismic principles is being considered.

ACKNOWLEDGEMENTS

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Mr. Andy Olson is the Product Manager - TRIAD with Rediffusion Simulation, Inc. He is currently responsible for directing the project engineering, development and marketing activities for the TRIAD sytem. He holds a Master of Science in Management from the U.S. Naval Postgraduate School, Monterey, California and a Bachelor of Science in Business and Industrial Management from San Jose State College, San Jose, California. Andy was formerly the Manager - Flight Operations, Plant Manager Palomer Flight Test Facility, and Manager Engineering Flight Test for Hughes Helicopters, Inc., where he was responsible for production flight test and pilot training on the Hughes Model 500 and 300 helicopters and engineering flight test on the Army Advanced Attack Helicopter AH64. Prior to Hughes Helicopters he spent over twenty years with the Marine Corps in aviation and data systems. Andy held the rank of Lieutenant Colonel, accumulating over 5000 hours of flying in twenty-three different types of aircraft including transports, helicopters and the AV8 Harrier.

F-16 & A-10A OFT SIMULATORS
FLIGHT SYSTEMS DEVELOPMENT & TEST

K.L. JOHNSON* AND M.P. BOGUMILL**

ABSTRACT

This paper discusses flight systems development and test issues of the Air Force's F-16 and A-10 Operational Flight Trainers (OFT) for flight controls, performance, and stability and control. Brief descriptions of the aircraft, simulators and their hardware, and flight systems software are presented. The basic design data base is described; simulator test techniques are presented; and some of the more interesting flight system simulation test problems and their resolutions are discussed. Probably the more basic reason for many of the A-10 OFT flight systems initial problems relates to the minimal involvement of user pilots during data development and flight system logic design operation. Conversely, the success of initial government flight systems testing of the F-16 OFT was aided by early user pilot involvement in system design and operation. This paper also contends that the greatest amount of transfer of training (simulator to aircraft) for flight systems operation and performance is obtained with a design philosophy which replicates cockpit features, visual cues, and the performance of the actual aircraft. The paper concludes with suggested future methods to improve simulation performance and test efficiency.

NOMENCLATURE

AOA	angle of attack
$C_{L\delta e}$	lift coefficient due to elevator
DAC	digital to analog converter
DPS	degrees per second
FS/g, δe/g	stick force and elevator per load factor
HST, PWT	high speed tunnel, polysonic wind tunnel
I/O	input/output
S/W	software
VVI	vertical velocity indicator

F-16A AIRCRAFT

The F-16A is a single-engine, single seat multirole tactical fighter with full air-to-air and air-to-ground combat capabilities. It has a wingspan of 33 feet with wing tip missiles and an overall length of 49.5 feet. With full internal fuel, full ammunition and two AIM-9 missiles, the gross weight of the aircraft is approximately 23,500 pounds. The maximum gross landing weight is 27,500 pounds and the maximum gross takeoff weight is 35,000 pounds, which permits the carriage of almost 11,000 pounds of external stores. The F-16A aircraft is powered by the F100-PW-100 turbofan engine, which is in the 25,000 pound thrust class. The fuselage is characterized by a large bubble canopy and an underslung engine air inlet. The wing tail surfaces are thin and feature moderate aft sweep (40^o). The wing is a NACA 64A204 airfoil which has leading edge flaps that are deflected automatically to enhance performance over a wide speed range. Flaperons are mounted on the trailing edge of the wing and combine the functions of flaps and ailerons. The horizontal stabilizers have a small amount of anhedral (10^o) and provide pitch and roll control through differential deflection. The vertical tail, augmented by twin ventral fins, provides directional stability. The primary flight control system is a full fly-by-wire system which does not use mechanical linkages or control cables between the cockpit and the control surfaces. This systems provides three-axis flight path control through the use of a side stick controller and rudder pedals.

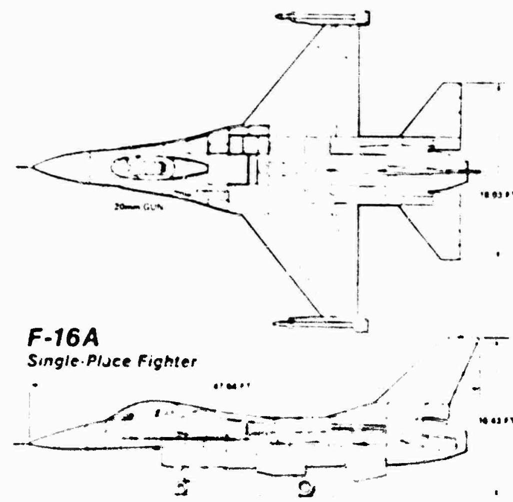


Fig 1 F-16A Aircraft

F-16 OPERATIONAL FLIGHT TRAINER

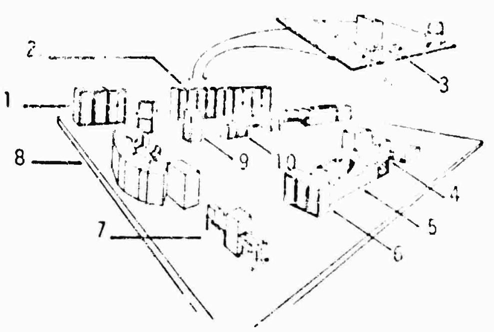
The F-16 Operational Flight Trainer (OFT) is currently nearing the end of a four-year production program and is being installed at various training sites throughout the United States, Europe, and Asia. The F-16 OFT is designed and built by the Singer-Link Corporation in Binghamton, New York and is intended to provide pilots with flight training that is directly transferrable to the F-16 aircraft. Through the use of the trainer, experience can be gained in the operational use of all aircraft systems. Pilots are able to practice tactical missions, both air-to-air and air-to-ground, with all possible weapon loadings. Emergency procedures can safely be practiced and the trainer can be "flown" to the limits of the aircraft's flight envelope to provide increased confidence and survivability.

TRAINER HARDWARE

Computation System. The current F-16 OFT consists of a computational system which comprises a complex of hardware units and structured software programs (Fig 2). The main computer consists of a central Nord-10/s 16 bit processor expanded four 32 bit Nord-50 processors. The Nord-10/s provides central control and supervision for all system I/O and program execution. The Nord-50 processors are dedicated to simulation system processing under control of the central Nord-10/s. The Nord-50 processors run in parallel, each contributing an uninterruptible one-fourth of the total Nord-10/50 computing power. Additionally, two Link-developed linear function interpolators (LFIs) are used to provide the aerodynamic data for flight handling characteristics of the trainer. Other hardware includes two disc drives, one a backup for the other, a Night Only Calligraphic Image Generation (NOCIG) visual system, signal conversion equipment (SCE), an actual F-16 Delco Magic 362F Fire Control Computer (FCC), a mechanoreceptor subsystem (MRCS) and a Sander's display system driving three CRTs, a light pen and three keyboards at the F-16 OFT instructor station.

Student Station. The cockpit of the simulator is an exact replica of an F-16 aircraft cockpit. It includes actual aircraft hardware for items such as the side stick controller, the Head-Up Display (HUD), the Radar/Electro-Optic (RDR/EO) system and the Fire Control Navigation Panel (FCNP).

All motion is simulated with a mechanorecptor cueing system (MRCS) consisting of 30^{o} reclined g-seat, anti-g suit, and a seat shaker. Unlike previous simulators, there is no hydraulic control loading because, just as in the aircraft, the simulator employs a fly-by-wire flight control system which interacts via signals from the stick and rudder pedals' force transducers through the signal conversion equipment directly to the flight control system software model to provide all necessary flight dynamics. Realistic aircraft and environmental sounds are reproduced by an aural cue system.



1. Power Cabinet
2. Nord Computer
3. Hydraulic/Pneumatic Pumps
4. NVS Display
5. Student Station (Cockpit)
6. Cockpit Peripheral Cabinet
7. NVS Support Equipment
8. Instructor Operating Station (IOS)
9. Mechanoreceptor Cabinet (MRCS)
10. 75 M-BYTE Disks

F-16A Trainer Simulator

On several, but not all, trainers a Night Visual System (NVS) provides visual cues for the pilot to fly take-offs, approaches, landings, air-to-ground weapons delivery, air-to-air intercepts, and and limited air refueling. It employs a conventional beamsplitter CRT display with an instantaneous field of view (FOV) of $\pm 22.6^{o}$ horizontally and $+13^{o}$ and -15^{o} vertically.

Instructor Operating Station. Finally, all of this is orchestrated at the instructor Operating Station (IOS). Designed to be operated by one instructor, the IOS includes three 21 inch alphanumeric CRT displays with a light pen, a radar/EO repeater with controls, selected flight avionics (repeater), a NVS repeater, functional keyboards, a three-axis joystick, and a communication system. Each CRT can provide real-time information of cockpit conditions, system malfunctions, instrument/navigation procedures, threats, or weapon delivery results.

FLIGHT SOFTWARE

The software is organized into modules which interact in a real-time simulation environment (Fig 3). The majority of the software is written in FORTRAN with some assembler language for better efficiency.

Each module is small (i.e., 100 to 200 statements), and has a well defined function such as module F500, Drag Coefficient. The Drag Coefficient Module calculates the total drag force coefficient due to aerodynamics including the basic aircraft and any perturbations from the clean configuration. The output of this module and several other aero coefficient modules interracts with the atmosphere module and equations of motion module to provide the flight dynamics for the simulator. Other modules are similarly grouped to provide engine dynamics, navigation, and weapons delivery simulation.

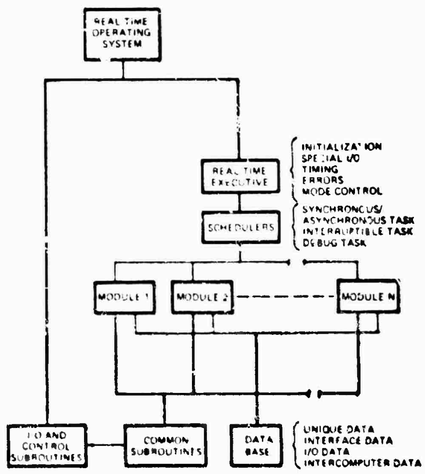


Fig 3 Software Organization

SIMULATOR DEVELOPMENT

Once the contract is let for the simulator, a large effort is spent in gathering data (Fig 4). Usually, sufficient data does not exist or there are anomalies in the data. Some examples for the F-16 OFT were: insufficient F-100 engine data, incomplete non linear rudder and flaperon effects, and incorrect aeroelastic modeling equations. Additional data must then be generated to cover voids.

This is expensive and time consuming. Once the data base is correlated, a software model is generated, debugged and refined.

As soon as possible during development, highly qualified pilot(s) should be brought in to perform a modified functional check flight of the simulator in order to identify any deficiencies in the flight regime. This was done with the F-16 OFT with excellent results.

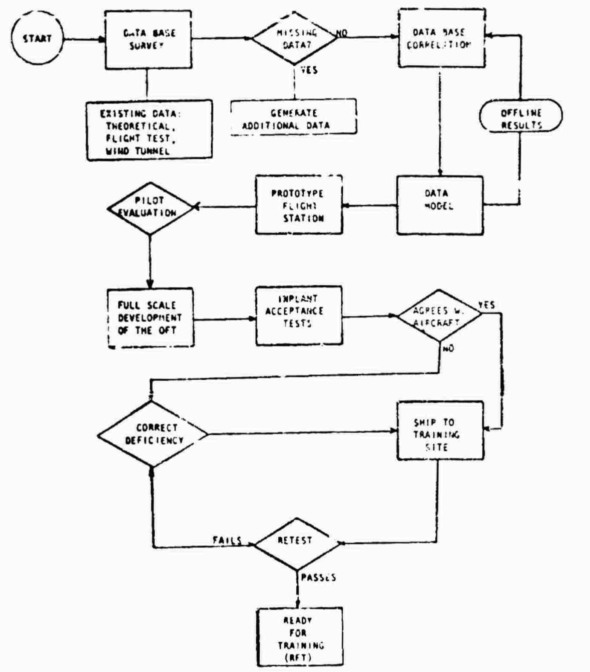


Fig 4 Simulator Development

Once Full Scale Development (FSD) and Quality Control (QC) checks are complete, extensive inplant acceptance tests with unit pilots begin. Several halts will probably occur as technical problems arise and are cleared by the contractor. If all goes well, the simulator passes several critical tests and is shipped to the appropriate training base. If all does not go well, then one or more technical deficiencies exist. If the deficiency is minor and does not effect training it will probably be waived for shipment and fixed prior to the ready for training date (RFT). If the deficiency is major then it must be corrected inplant. For the F-16 OFT follow-on simulators, retesting consisted of condensed testing of the necessary areas to ensure a complete and accurate system.

TEST PROCEDURES

In order to evaluate the complete F-16 OFT system over 4,000 pages of Acceptance Test Procedures (ATP) were written and incorporated into ten volumes. One of these volumes, volume seven, contained the performance evaluation tests. It consisted of: weight and balance checks, atmosphere checks, speed power tests, engine performance, and both static and dynamic flight characteristics.

Weight and balance tests were rather straightforward readouts of gross weights, centers-of-gravity, and moments of inertia for several F-16 configurations. Similarly, the atmospheric checks evaluated proper temperature lapse rates, airspeeds and mach number for standard (+15°C) and nonstandard days (-20°C, +40°C) and also checked for correct wind, turbulence, and gust effects.

The Speed Power tests provided the first detailed comparison of the performance of the simulator with that of the aircraft. These tests consisted of level accelerations/decelerations, rates-of-climb, and times-to-climb. The level acceleration tests were run at several fixed altitudes from sea level to 50,000 feet at maximum and military power settings. These tests are highly dependent upon an accurate engine model for thrust and inlet ram drag, and an equally accurate model for aircraft drag. The rate-of-climb (R/C) tests were run differently in the OFT than in the aircraft. R/C curves were generated for three different gross weights at sea level, 10,000 feet, and 30,000 feet. The trainer was then evaluated against them by freezing the altitude and allowing the pilot to vary the true airspeed by changing the pitch attitude. Thrust was kept constant at either military or maximum power settings and gross weight was maintained by freezing the total fuel. These tests became more difficult at the higher altitudes and gross weights due to its sensitivity to airspeed and pitch changes in this regime. The time-to-climb tests were more dynamic and, therefore, similar to those in the aircraft. Two tests were run, one in military power and one in maximum power. Both were run from sea level but timing was not started until the trainer passed 10,000 feet in order to allow the pilot to stabilize his climb attitude. The pilot initially maintained a constant airspeed (400 KIAS for military power; 550 KIAS for maximum power) until reaching 0.9 mach (mil power) or 1.5 mach (max power) and then held constant mach until completion of the test. Again, as in the R/C tests, it became difficult to match the data at the high altitudes primarily due to lower thrust available, pitch sensitivity, and pilot technique. Longitudinal maneuvering flight characteristics were evaluated using constant airspeed fixed altitude wind-up turns to 7 g's to determine control surface variations with load factor. Several gross weights and configuration were analyzed at 10,000 and 30,000 feet. As the angle of bank and the g-loads increased most pilots had difficulty maintaining mach number/airspeed even with altitude frozen. Repetition improved the pilot's ability and the test results. Longitudinal trim checks were also made for various configuration changes such as gear, flaps, and speed brakes extension and retraction. Lateral trim checks were performed by steady-state sideslips in which the pilot maintained a wings level sideslip of constant rudder pedal force. The rudder pedal force was varied up to full rudder deflection for each of several airspeeds, altitudes, and configurations. Results for sideslip angle ( ), rudder deflection, and differential flaperon were then compared with the aircraft data. Lateral trim was also checked for asymmetrical loads.

Dynamic stability flight characteristics were evaluated by first comparing the longitudinal short period dynamics with those of the aircraft. A strip chart recorder was used to record longitudinal stick force, stabilator position, pitch rate and attitude, angle of attack, and load factor while the automatic test features of the computer were used to input a pitch force doublet. Tests were run at three basic configurations, three different altitudes and several airspeeds. Similar procedures were used to evaluate the roll mode. Again the automatic test feature was used with the strip chart recording roll force, differential flaperon, roll rate, and roll attitude. From these tests, times to roll 90°, 180° and 360° for several airspeeds, weights, and configurations were compared with flight test data. Finally, the Dutch Roll mode was investigated using a rudder doublet (automatic function) and recording rudder pedal force, rudder deflection, yaw rate, roll attitude, sideslip angle, lateral acceleration, roll rate and differential flaperon.

Tests were also performed to evaluate 1-g stalls and take-off and landing performance. The last test performed was an overall pilot evaluation of the entire flight envelope. This was performed by a highly qualified F-16 flight test pilot whose comments were used to further improve the simulator data base.

TEST RESULTS/PROBLEM AREAS

One technique which has provided Air Force engineers with insight into potential problems in the flight handling area is to have the pilots "fly" simple profiles during their first time in the simulator. This allowed discrepancies, which might not otherwise be evident, to surface. One such discrepancy was noted by several pilots. Their comment was that the simulator required excessive force to "unstick" from the runway during rotation and lift-off. Contributing factors were a limited field of view visual system which may not have provided sufficient cues for rotation and lift-off and a fixed-stick controller which the pilots were not accustomed to using. The primary cause, however, was a non-linear load curve for the main landing gear which was approximated by linear equations. Additional break points were required in order to "smooth" the curve to fit the actual aircraft performance.

Another discrepancy was noted during the landing phase. Just prior to touchdown almost all pilots entered a rolling PIO (pilot induce oscillation) on their first landing in the simulator. This was also noted initially on the A-10 simulator. As the number of approaches and landings increased, the rolling tendency decreased to zero. The primary cause for this appears to be a lack of visual cues near the terminal phase of the approach. The pilot then overcontrols the roll axis. As experience grows, the pilots "learn" to slow their roll inputs during this phase to effectively eliminate this problem.

As mentioned previously, it was difficult to test the time-to-climb above 40,000 feet due to its sensitivity to airspeed and pitch. Several iterations of this test were required before satisfactory results were achieved. In this case, the data was correct but the test procedures were difficult to follow.

Perhaps the area of highest risk was in the software development for the F-100 engine. The actual F-100 engine in the F-16 aircraft is operational throughout a very broad flight envelope with rapid changes in engine demands. In order to properly handle this, a cycle analysis design approach was used to model the dynamics of each engine section. From the onset this effort was beset with problems ranging from missing data, especially transient data, to personnel changes. Two years were required to perfect the engine simulation.

A second problem area of the engine development existed in the Back-up Controller (BUC) which provides the fuel flow rate to the engine in the event of failure of the primary Unified Fuel Control (UFC). Both hardware and software problems occurred to hamper testing. Once the hardware was fixed, pilot comments became very important in isolating software problems and additional data was then sought to correct them.

A-10A AIRCRAFT

The A-10 aircraft is a single place close air support aircraft built by Fairchild Republic Company, Farmingdale, New York. It is powered by General Electric TF34-GE-100 engines having a maximum installed thrust of 9,000 pounds per engine. The maximum gross weight of the aircraft is 47,500 pounds. The engine is a high bypass turbofan with a single fan rotor, fourteen stage compressor and six turbine stages (See Fig 5). The aircraft has a length of 53.5 feet, a wing span of 57.5 feet, and a wing area of 405 square feet. The wing airfoil is an NACA 6716 inboard of the landing gear pods and an NACA 6713 outboard. The wing contains four panel, three position flaps, aileron and aileron tab surfaces, and eight pylon weapon stations; three additional pylon stations are located on the fuselage. The ailerons consist of upper and lower panels which also function as speedbrakes when moved symmetrically. The empennage consists of twin vertical rudders, a horizontal stabilizer, and elevators with elevator tab surfaces. The horizontal stabilizer and vertical stabilizer are NACA 64A013 airfoils. The armament system includes a 4,000 round per minute 30mm seven barrel gun. The flight control system is designed to operate with single or dual hydraulics shut down; the latter case is called Manual Reversion. Without hydraulic power, roll control mechanically transfers from aileron surface control to aileron tab control by means of a roll tab shifter device near the control surfaces. Mechanical disconnect devices, in both the pitch and roll control axes, free the control stick to operate in one of two separate paths in both pitch and roll in the event of a mechanical linkage jam.

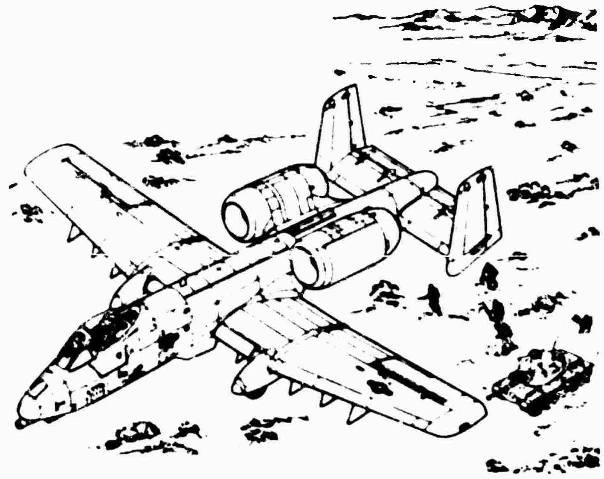


Fig 5 A-10A Aircraft

A-10A TRAINER SIMULATOR

Reflectone, Inc., of Tampa, Florida builds the A-10A Operational Flight Trainer for the Air Force through an initial 1976 contract with the Simulator Systems Program Office. The principal mission of this trainer is to provide the capability of procedures and proficiency training to pilots required to fly the A-10A aircraft in fulfillment of its mission to navigate, seek out and destroy ground targets. The trainer provides the means of developing proficiency in all phases of instrument flight, including ground operations, takeoff, enroute navigation, holding, penetration, approach, and landing under both normal and emergency conditions. The visual system permits practice in normal and emergency procedures under simulated night visual conditions. Experience will also be gained in selection and release procedures associated with the basic armament system and simulated electronic warfare (EW) equipment.

TRAINER HARDWARE

The trainer hardware and floor layout are shown in Figure 6. The primary computer capabilities consist of: Three System Electronics Laboratory (SEL) 32/55 computers (Units 1), an MDEC Vital IV system consisting of a Varian Image Generator Processor and Visual Display Unit (Units 7 and 2), an LSI-11 Minicomputer, aft of the cockpit station, for control loading modeling (Unit 8). Additional hardware systems are the Instructor Station (Unit 3), the Electronic Warfare Simulation Cabinet and Console (Unit 4), Audio Cabinet System (Unit 5), and Hydraulic and Electrical Power Equipment (Unit 6).

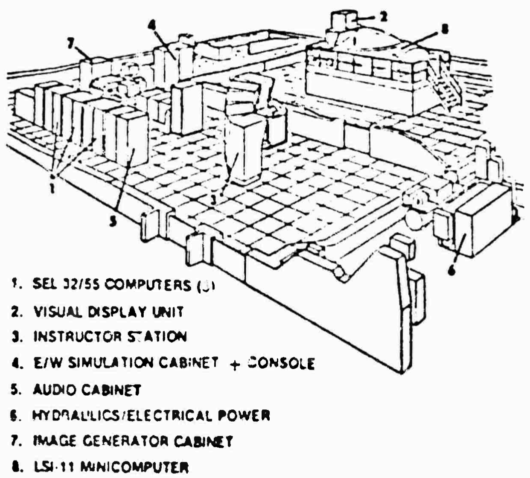


Fig 6 A-10A Simulator Facility

FLIGHT SOFTWARE

The software is primarily coded in Fortran with some assembly coding for the non-real-time programs. The trainer S/W system contains approximately 300,000 lines of code of which all are disc stored. The flight control system for the A-10 trainer simulator is a digital control loading system (DCL) designed and built inhouse by Reflectone, Inc., of Tampa, Florida. The DCL represents a novel method for simulating the control systems of an aircraft. The traditional method has been a system consisting of sensors, mechanics, hydraulics, drive electronics, and modeling ties together with some I/O interface to a host CPU. In this design, the modeling electronics (basically an analog computer) was replaced with a digital computer. The control system modeling of the aircraft is then performed by the digital computer software. I/O interchange to the host SEL computer is now performed by direct memory address (DMA) exchanges between the LSI-11 digital control loader computer and the host CPU.

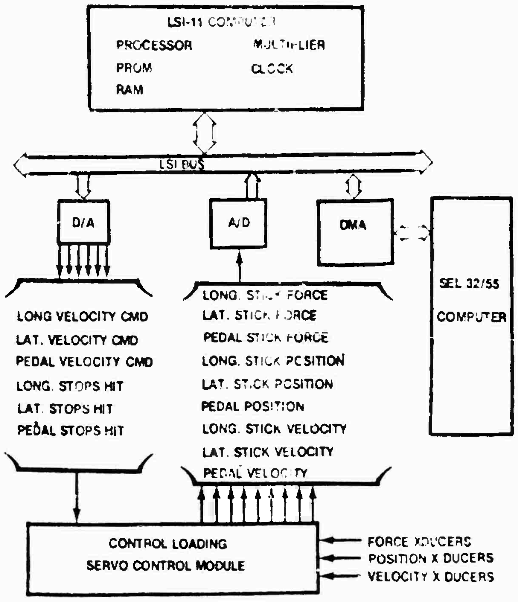


Fig 7 Digital Control Loading Subsystem

The propulsion module consists of approximately 600 lines of Fortran code and is executed at 10Hz with rectangular integration. Its primary outputs are net thrust and ram drag to the aerodynamics module, fuel flow to the fuel systems module, and thrust and engine speed to an aural cue module. The flight module consists of approximately 550 lines of code and performs calculations and summation of all aerodynamic forces and moments acting at the aircraft center-of-gravity. These forces and moments are a function of configuration, control surfaces, engine thrust, angle of attack, sideslip, body angular rates, and environmental conditions. The module data is in approximately 60 percent tabular and 40 percent equation form. The flight equations of motion are computed at 20Hz using a rectangular integration scheme.

DATA BASE

The total system design data base is best appreciated by realizing that a top level document listing the design references contains over 500 individual entries. The flight systems list is 30-40 percent of the total and includes flight test reports from Fairchild Republic Aircraft and the Air Force Flight Test Center as well as aircraft technical orders, engineering reports and drawings. Additional government reports from the Air Force's Tactical Air Command, Flight Dynamics Laboratory, and Human Resources Laboratory were also included in the design data base.

The aerodynamic and propulsion data base is currently a mix of wind tunnel, flight test and data variants due to pilot evaluation. The basic set of data and equations are based upon a cruise configured A-10A. Data changes due to configuration changes, external stores, power and hydraulic status are generally modeled as incremental effects to the cruise configured aircraft. Aerodynamic effects due to buffet, ground effects, and asymmetric controls and malfunctions are also modeled. Wing stall conditions are computed on each wing side individually based on AOA and tip roll rate. Side force due to rudder and lift force due to elevator are modeled as geometric multipliers of yawing moment due to rudder and pitching moment due to elevator respectively. Reductions in lift and a nose down pitching moment due to the absolute value of sideslip are also included. These values are 15 and 10 pounds of lift coefficient and pitching moment respectively per degree of sideslip.

The original aerodynamic data S/W load was based almost exclusively upon wind tunnel data primarily obtained from 1/10 scale model tests of the A-10 in the NASA Langely 7x10 ft HST and the Ames 12 ft PWT. This data resulted in poor lift/moment effects due to power induced flow particularly with secondary control surfaces, i.e., speedbrake and flap deflection. Wind tunnel roll control effectiveness for the cruise configuration was also excessive but identified and documented during flight test. Much of the flight test derivatives identified in AFFTC-TR-77-1 were incorporated into the simulator; however, these derivatives primarily addressed the low angle of attack regime in a cruise configuration. The side force due to aileron and normal force due to elevator were incorrect and not incorporated; the lateral accelerometer location had been mislocated in the computer derivative extraction program resulting in the incorrect side force derivative; wing to elevator center-of-pressure geometric constraints for $C_{L\delta_e}$ computation had also not been entered into the program. The point in mentioning these data discrepancies is that the A-10 aircraft program had a huge aerodynamic data base with inaccuracies and conflicting data which required considerable effort to determine and delete in order to arrive at a data base acceptable for trainer simulation development. Although a huge data base existed, there were also considerable gaps that needed definition; some of these were: (1) external stores mass and inertial properties, and rack and pylon locations, (2) definition of control surface hinge moment characteristics relevant to cockpit control forces during Manual Reversion Flight (no hydraulics).

TEST METHODS

This will be described in a broad sense relating to test effectiveness and efficiency. Air Force simulator acceptance testing has traditionally been very time constrained by comparison with aircraft testing. In this regard, test management coupled with test planning and sequencing along with test techniques and data were very critical to test accomplishments. In reflection, insufficient government involvement during contractor inplant testing of the first article and an abbreviated Test Readiness Evaluation prior to large scale start of government testing resulted in considerable misunderstanding between Air Force and the contractor during subsequent A-10 simulator testing. Also, insufficient use was made of TAC/Test Pilots during contractor inplant testing; results during this period were also not sufficiently documented or remedied. In addition, simulation peculiar test procedures for determining system performance were not sufficiently detailed to allow efficient and large scale official government testing. Detailed flight performance was attempted prior to a thorough computer systems operation checkout resulting in poor flight system test efficiency. Many computer halts and dropouts were encountered which hampered the flight performance evaluation.

TEST EQUIPMENT

Calibrated force gages (load cells) were used by the government to calibrate S/W values for cockpit control forces. A single eight pen strip chart recorder (SCR) was used to provide a continuous record of flight performance and dynamics; a secondary and somewhat unplanned evaluation fallout was its use in identifying sources of computer halts and interrupts. An X-Y-Y plotter was also used and was extremely useful in generating flight control gearing curves of force and position. The plotter graphically portrayed undesirable control force to position "ratcheting" associated with the digital control system implementation. This analog test equipment was provided drive signals by a S/W routine containing 120 internal computer signals; they were converted for display through DACs updated at 2Hz. Additional test display aids were the primary cockpit instruments repeated on the instructor console, i.e., ADI, altimeter, VVI, airspeed, and HSI; these instruments were also repeated graphically on Sanders CRT display pages along with engine parameter bar graphs. This information was very helpful in communicating and understanding pilot evaluations and concerns. There were additional CRT display pages that were very helpful for the evaluation; a control parameter page showing cockpit control and surface positions and a flight parameters page listing weight, configuration, airspeed, engine, environment, and acceleration/rate/attitude response.

TEST TECHNIQUES

Procedures and test results for simulation qualification were contained in a document called the Acceptance Test Document. For flight systems testing this document contained a large assortment of flight test results primarily obtained from two preproduction A-10A aircraft S/N 73-01665 and 73-01667. (These flight test report results are references 1 and 2.) The test techniques used in simulation testing paralleled flight test techniques to a large degree. Flight and simulator sideslip were done with steady heading rather than wings level. For longitudinal and lateral-directional dynamics, actual flight control surface signatures were duplicated and used to drive simulator response. Freezing altitude during many of these tests reduced pilot workload and improved data correlation; this could be done without affecting the calculation or display of velocity or attitude. Prior to these system performance tests, lengthy tests had to be performed to validate the environment, i.e., the atmospheric model, pressure sensitive instruments, and weight and balance. One-G stalls were determined from SCR data of lift coefficient, G's and AOA. These AOA values correlated well with a more easily observable VVI break on repeater instruments during one-G stalls.

Maneuvering stability and stall pitch out were tested during windup turns at constant airspeed. Post-stall gyration, spin, and spin recovery were evaluated against specific flight time history signatures. An attempt to replicate stall/post-stall flight control inputs were done manually with a control input/stick box diagram and written maneuver descriptions.

TEST PROBLEMS

A number of performance differences were observed during testing of the No. 1 simulator unit. As a consequence of this testing, approximately 1,500 test discrepancies were identified, of which 300 were against flight systems; of these, 40 percent were system logic errors, the remainder were system performance errors ranging from the manner in which rudder servo valves shutdown during a single channel SAS malfunction to the dynamic response of the VVI.

Attitude Changes. Slow yaw, pitch, and roll control attitude changes were observed on instruments and the visual system following a controls free, careful one-G trim setup. The motion drift was caused by fluctuating surface control positions from the LSI-11 digital control loader into FFLITE, the aerodynamics module, causing subsequent attitude changes. It was primarily solved by creating a S/W statistical automatic fine tuning loop for the flight control system in pitch, roll, and yaw to account for small varying null positions due to the hardware. This logic looks at stick and pedal velocity, and force over 64 sampling periods (less than one second at a sampling rate of 156Hz) then statistically averages the values and uses them as new and current bias and null forces for servo-value commands. A secondary fix involved a separate hold (clamp) circuit for the control surfaces to eliminate small signal disturbances. Stick position and stick rate, surface control and trim positions are used in the hold circuit logic. When these positions and velocity signals are within a small magnitude level, a new current trim position is used.

Tracking/Strafing. The pilot control workload associated with capturing and maintaining the Head-Up-Display (HUD) gun cross on the target during acquisition and tracking was excessive by comparison with the aircraft workload required. This was an early recognized deficiency of the simulator which was also one of the last problems corrected; it was solved by deviating from design yaw stability augmentation criteria. The design criteria called for an aileron to rudder interconnect (ARI) gain of .2 degrees of rudder per degree above 240 knots along with a yaw rate washout circuit of four seconds (4s/4s+1). This SEL computer circuit was modified during pilot evaluation to a fixed value at all airspeeds of .8 degrees per DPS for the ARI rate damper. This change not only resulted in clearing this discrepancy but also another characterized by excessive yaw and roll during final landing approach. This change appears to be a situation where some undetected (negative) characteristic of the simulator was corrected by an intentional deviation (negative) resulting in a (positive) acceptable performance result. Prior to making this change, the visual brightness of the gun strafing target was poor and was subsequently brightened. This visual change reduced pilot workload but was not of a sufficient nature to preclude this yaw SAS change.

Take-Off Rotation Speeds. Two problems existed which, when recognized as being related, were both corrected with a single design change. The first was the minimum rotation speed at take-off which was higher than the aircraft. The other problem was an excessive pitch down with a throttle chop (the aircraft has negligible initial pitch change with throttle motion). A review of the software model engine line-of-thrust and design data showed that the pitching moment associated with tailpipe curvature (4.5 degrees up) had not been accounted for. Inclusion of this effect in the model solved both the higher rotation speed and the initial pitch up with a throttle chop. An added benefit was the readjustment of C_{mo} values back to magnitudes published in flight test reports. Prior to recognition of the tailpipe curvature effect, the flight values of C_{mo} had been considerably modified to correct trim elevator differences between the simulator and flight results.

Pitch/Roll Sensitivity. This problem still exists to some degree on the simulator; it is an excessive attitude response for small pitch and roll control inputs. Previous changes to the simulator have not corrected this issue: the aileron actuator model had been slowed down from a 50 millisecond first order lag to a 120 millisecond lag; in addition, aileron control surface aerodynamic effectiveness was reduced for deflections under five degrees. Design data (wind tunnel and flight test) were generally lacking-only showing roll effectiveness for much larger control deflections.

Flight Test-Simulator Recommended Improvements

In order to improve simulator quality and test effectiveness, we recommend the following improvements in the data base: (1) Surface authorities and maximum rates relative to airloads/airspeed, (2) Identification of any control surface effectiveness reduction for small deflections (e.g., 3 degrees), (3) Cockpit control trim motor transient characteristics relative to surface and stick motion (e.g., no. of clicks to full authority), (4) Flight control system damping and frequency characteristics for normal and degraded hydraulic and electrical power operation, (5) Post stall dynamics and departure characteristics, (6) Control response sensitivity for the power approach configuration, (7) Flight test document expansion of written descriptions of aircraft peculiar characteristics even if the data base does not fully explain the phenomena, (8) Identification of conflicting data between viable sources (flight test vs. contractor), and (9) improved communication between the aircraft test community and the trainer simulation community.

TEST METHODS

The following recommendations are suggested in simulator and flight test methods to improve simulator efficiency and quality: (1) Combine AOA and control surface trim definition with speed power test during aircraft flight and simulator testing. (2) Freeze simulation altitude while allowing accelerations, velocities, and attitudes to change-to reduce pilot workload during speed stability, maneuvering stability and flight dynamics tests, (3) Better describe how flight test configuration trim changes are performed (e.g., constant attitude, power, altitude). There is an inherent potential for simulation dynamic cue mismatch (e.g., visual, cockpit instruments, flight modules operating at different computational update rates) and fewer (than aircraft) cues available in a simulator. Because of this, additional cockpit instrumentation flight characteristics are required. This cue data should be time tagged to normal aircraft response parameters (e.g., a video camera and recorder). We recommend a cyclic Bode frequency response test at fixed airspeeds. Flight test pilots should also "fly" the simulator as soon as possible to identify deficient areas.

Rather than perform initial flight simulation testing in a segmented classical sense, we suggest that a few aircraft tests be performed specifically structured for simulation use. These tests would be combined expanded functional check flight complied with operational scenarios with a fully instrumented aircraft containing pilot voice recording and a video recorder for instrument response information. This same test profile can then be flown on the simulator in the same manner again recording pilot comments and measuring simulator performance. A method of this nature would allow early identification of significant simulation flight system deficiencies.

PLANNING METHODS

Air Force acceptance of First Article Simulator Systems has been lengthy with unplanned extensions of test schedules because of the unanticipated large number of serious Test Discrepancies. This problem can be minimized if certain concepts are emphasized such as: (1) Providing briefings of system operation and flight characteristics to contractor personnel, (2) Showing, and possibly demonstrating, the aircraft to contractor personnel, (3) Identifying data base milestones within the contract, better organize the design documents, especially their accuracy, currency, and completeness, (4) Assuming that additional aircraft flight data would be necessary for design, thereby dedicating some flight missions for simulation data purposes, (5) Developing a "prototype" flight station as a design tool-between the User pilots and design personnel-for early correction of system operation and flight performance problems.

TRANSFER OF TRAINING

The Air Force spends sizable sums of money to replica aircraft systems operation and displays, flight performance and dynamics, and corresponding motion and visual cues. Questions arise concerning the need for this large design and cost effort. The authors believe that high fidelity flight performance and dynamics are necessary but not sufficient for high Transfer of Training. Some additional and necessary factors are: (1) Training scenarios that reflect an operational mission, (2) Induced psychological stress, and (3) Sufficient visual/motion cues appropriate for a task. If system training requirements are not clearly defined by the USER, or misunderstood by the procuring agency, a trainer can easily be developed with capabilities not totally suited for training. Both the A-10 and F-16 simulators have high fidelity flight performance and weapons capabilities; however, a realistic ground attack or visual landing approaches can hardly be trained properly because of their single window visual systems. Without the possibility of an accident occurring, it's difficult to obtain appropriate stress and workload levels. Minor system performance errors can have large impacts to positive transfer of training for new students who tend more to generalize single issues into poor total system performance. Transfer of training for the Manual Reversion flight now for the A-10 is expected to be less than desirable at this time because force/feel characteristics for trim, configuration, and power changes do not sufficiently reflect the aircraft.

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EMPHASIS ON RELIABILITY, MAINTAINABILITY & QUALITY ASSURANCE

CAPT J.R. SEELEY, USN, Chief Naval Material, Assistant Deputy
for Reliability, Maintainability & Quality Assurance

This is an invited presentation and will be included in Volume II of the Proceedings

THE MILITARY AIRLIFT COMMAND AIRCREW TRAINING DEVICES PROGRAM

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ABSTRACT

This paper discusses the Military Airlift Command's (MAC's) current and future aircrew training programs. Emphasis is placed on the aircrew training program structure, the use of simulation, and the benefits derived from simulations. The paper's purpose is to provide a brief history of MAC simulation and discuss the command's training philosophy. Current programs and their problems are outlined with a brief look at MAC's future plans.

Aircrew Training devices in the Military Airlift Command (MAC) are an integral part of the training programs. Without simulation the overall readiness of MAC's forces would be hindered in today's environment. Increased fuel costs and decreased flying hours make additional aircraft training difficult. Simulation must be used to fill the void.

The mission of the Military Airlift Command is to maintain the military airlift system and services in a constant state of readiness. It must be able to respond immediately to any location on the globe. In order to maintain this state of readiness, an effective aircrew training program is essential. Since the early '50s, MAC has relied heavily on flight simulation in training its aircrews. As the simulation industry evolved, training programs took advantage of the advances. Today simulation is essential to MAC's readiness. Training programs are structured using the instructional systems development (ISD) approach to produce efficient and effective programs. This produces a mix of classroom, learning center, simulator, and flying activities. Beyond training critical emergency procedures which cannot be trained in the aircraft, crews receive training in crew coordination, normal procedures, noncritical emergency procedures, and instrument flight through simulation. The time logged in the simulator is credited toward initial qualification and currency in MAC aircraft. Simulation allows MAC to effectively perform its day-to-day and wartime mission with increased efficiency in crew performance and savings in flying hours.

MAC's airland mission is similar to that of the commercial airlines, therefore, their training programs are also similar. In addition, MAC has an additional air refueling and a tactical low level/airdrop mission which have unique training requirements. Although the mission is similar, the experience level of the average MAC student is much lower than that of the average airline student. The average MAC copilot student has just finished undergraduate pilot training and has approximately 150 to 200 hours. The normal aircraft commander candidate usually has 1000 to 1800 hours which is much lower than the average airline captain candidate.

HISTORY

In the early 50's, the Military Air Transport Service (MATS), the forerunner of MAC, used flight simulators to train transport aircrews. MATS' first simulator, a C-97 aircraft flight simulator, was delivered on 15 October 1952 and became operational on 1 December 1952. By June of 1953, MATS had one C-124 and three C-97 flight simulators operational at its West Palm Beach International Airport facility. Training hours in these simulators were substituted for a portion of the total flying hours required to train students in these aircraft.(1) In addition to initial and upgrade training, the Continental Division (responsible for this training) was tasked to establish simulator refresher training courses in the C-97 and C-124 for the entire command. These courses were to be used to provide training for operational aircrews. The training was designed to standardize procedures and teach additional emergency procedures which could not be accomplished during actual flight operations. (2)

The first aircrew training courses were more or less experimental in regard to the mix of aircraft and simulator time. The simulator proved to be a valuable supplement to the aircraft for aircrew training. But the questions of frequency, purpose, and the manner in which the simulator should be used had not been fully explored.

Training Effectiveness Study

To partially answer some of the questions concerning the use of simulators, the first training effectiveness study for MATS was conducted by the Crew Research Laboratory of the Air Research and Development Command. This study was undertaken to compare the effectiveness of various types of transition training for the C-97. Three different mixes of aircraft and simulator time were evaluated along with three different sequences of simulator practice: before aircraft, mixed, and after aircraft.(3) The major findings were: 1) the low aircraft/high simulator time condition was clearly inferior to other conditions for student aircraft commanders. 2) the simulator first sequence was clearly superior to other sequences 3) the study further concluded that a relatively equal mix of simulator and aircraft time not only proved to be the most cost effective, but yielded the same proficiency results as training with more aircraft and less simulator time.(4) A similar study was conducted for the C-124 aircraft and yielded like results.(6)

Since these early days of crew training at West Palm Beach, simulators have played a key role in MAC's overall training program. As a command, MAC has always operated with simulators as a means of reducing actual aircraft flying training time. However, it is difficult to document any savings because the command never operated without simulators.

The majority of MAC's existing training programs are based on those programs developed in the early 70's and utilize simulators procured in the early 60's. These programs and devices met MAC's needs in the past, but the operational mission and training tasks must change to meet MAC's ever changing combat role. The need exists for MAC to enhance its aircrew training by using improved training techniques and fully exploiting aircrew training devices. Effective training devices must be acquired to meet the command's training needs.

COMMAND PHILOSOPHY

The Military Airlift Command's aircrew training goal is to provide an efficient, individualized training program. To accomplish this goal, MAC has acquired aircrew training devices (ATDs) ranging from basic mockups to full mission simulators. The programs are structured so that students progress from the simple devices through the most complex trainers before going to the aircraft. Students must demonstrate proficiency in one phase prior to moving to the next phase.

MAC began applying Instructional System Development (ISD) methodology to its flying training programs in Feb 72. This management technique has resulted in the identification and procurement of numerous synthetic training devices which were essential to improve the quality of training while reducing training costs.

Training Devices

Aircrew training devices as described in AFR 50-11 fall into several categories. MAC's use of these interactive devices is detailed as follows:

Mockups and Part Task Trainers are simplified representations of aircraft systems or component parts. They are used to:

a. Introduce and train specific procedures and tasks.

b. Familiarize and demonstrate specific system operations.

c. Practice and evaluate simple tasks.

Cockpit Procedural Trainers are training devices which provide the student with a realistic cockpit environment in which most of the system controls and indicators operate properly. These devices are used to:

a. Provide initial, continuation, and remedial training in normal, alternate, and selected emergency procedures which do not result in significant flight dynamic problems.

b. Provide initial and recurring training in ground emergencies, interior preflight, and auxiliary power unit operating procedures.

c. Provide loadmaster training in the operations of cockpit controls where required (doors, power units, etc).

d. Provide maintenance crew engine runup and troubleshooting procedural training.

Instrument Trainers provide a realistic cockpit and controls with an operable navigation system and aerodynamics package to allow students to perform instrument maneuvers. These devices are used to:

a. Teach general techniques and procedures for instrument flying.

b. Maintain instrument proficiency of personnel assigned to fly other than primary mission aircraft.

c. Augment flight simulator training programs.

d. Supplement aircraft training of pilots; maintaining proficiency in instrument flying.

e. Provide any other special training deemed necessary by local commanders.

Flight Simulators are fully instrumented advanced training devices which provide full system logic. The operational flight trainers normally do not have a visual system whereas the weapon system trainers do. These devices are used to:

a. Fully train coordinated aircrew performance in dynamic scenarios which require proper prioritization or management of cockpit actions.

b. Train normal, alternate, or emergency procedures which cannot be trained in the aircraft due to lack of control of the environment (crosswinds, ceiling, visibility, pressure altitude, temperature, wind shear, etc).

c. Train proficiency and required alternate/emergency procedures which pose a significant flight dynamic control problem that cannot or should not be performed in the aircraft due to safety considerations (i.e., runway aborts, two-engine approaches, emergency descents, stalls, etc.).

d. Accomplish required proficiency maneuvers, training tasks or currency events for which the ATD is certified.

e. Conduct aircrew chemical warfare training.

f. Conduct electronic warfare training.

g. Conduct required flight evaluations to the extent the ATD is certified.

Training Device Use

In order to have the devices available to accomplish all required training, we have established the following priority guidelines for the use of all MAC aircrew training devices:

a. Research of flight safety items.
b. Remedial training.
c. Annual refresher training.
d. Special qualification training (i.e., air refueling).
e. Transition/upgrade training (except in designated formal schools where this is the highest priority).
f. Proficiency training (practice and currency "event" accomplishment).
g. Maintenance crew training.

The guidelines have been established based on historic simulator use and current instructional technology. Aircrew training devices are essential in providing an effective combat ready MAC crew member.

To insure that sufficient time is available for maintenance support, the maximum usage of older ATDs is 16 hours per day, 330 days per year or 5280 hours annually. On newly procured devices, the maximum use is 18 hours per day, 330 days per year or 5940 hours annually. The increased reliability of the new ATD's allows them to be used more than the older ones.

CURRENT PROGRAMS

MAC currently possesses 26 flight simulators (operational flight trainers or weapon system trainers), 12 cockpit procedural trainers, two instrument trainers, and numerous part task trainers. These training devices are used in our C-5, C-141, C-130, C-135, HH-53, and CH-3 training programs. Additionally, MAC contracts for simulator time to support the C-6, C-9, C-12, CT-39, C-137B and the C-140 aircraft training programs. C-5 and C-141 initial air refueling training is also contracted on an interim basis.

Initial Training Program

MAC is committed to the concept of a centralized training facility to conduct the majority of its aircrew training. This concept provides a standardized product in the most cost effective means and now includes the basic engineer, aircrew instructor, airdrop, air refueling, and tactical low level/formation training as well as initial qualification training.

All MAC formal schools are similar. They consist of academic, simulator, and flying phases. The time at each school varies according to the aircraft and crew position. The academic phase consists of programmed classroom lectures, seminars, self-paced instruction, and the use of synthetic trainers. The simulator phase of training includes simulators with motion system and visual systems. These devices allow the student to be taught, practice his skills and then be evaluated on his performance prior to advancing to the flight phase. The simulators now in use by MAC are limited in the scope of tasks they can train. The aircraft is used to complete the training and to allow the student to gain self confidence in the operation of an aircraft. Students graduate qualified to perform the MAC mission with a minimum of local orientation training upon arrival at their operational unit.

Continuation Training Program

Continuation training is a program that consists of required flight currency events, block training and simulator refresher/proficiency training. Wing learning centers provide aircrews their annual review of ground training items using slide tape, video tape, and hands-on training programs. Aircrews are also required to maintain their currency by performing a specific number of currency events (i.e., precision approaches, landings, etc.) within specified time periods.

Annual Simulator Refresher Training program is similar for all aircraft and is required by Air Force and MAC regulations. A typical refresher course lasts 5 days and normally consists of 20 simulator hours. Each day crews fly a 4-hour mission representative of a typical MAC route.

The fifth day of the refresher course is normally a standardization evaluation flight. On all missions, the pilots change seats at the end of the first 2-hour segment. During the mission, which is usually run without mission freeze or repositioning, the crew is confronted with various situations which require crew coordination and decision making. The instructor on these missions controls the pacing of the mission as well as the content (within prescribed guidelines). He guides the student, when necessary, through the situation with immediate feedback, alternate actions, and then follows up with a post mission debriefing.

During the week-long course, all aircraft systems are covered. The student must be able to operate the system, recognize malfunctions, analyze the problem, and take the appropriate corrective actions. Numerous realistic malfunctions and emergencies are presented. Additionally varying instrument situations, including category II ILS training in the C-141, are included. This training not only includes minimum visibility and ceiling approaches, but other weather phenomena such as low level wind shear.

In addition to the actual time spent in the training device, each mission includes a 2-hour premission briefing. This briefing is controlled by the instructor, but normally is more of a discussion than briefing. It covers the systems and procedures to be presented on that mission. Following the mission, a debriefing of the major points of the mission are covered by the instructor. At this point the students have a further opportunity to discuss systems, procedures, and alternate courses of action for varying situations.

Simulator Proficiency Training program is two to three days in length and provides 8 to 12 hours of simulator time. It concentrates on mission training and skill maintenance. For strategic airlift, the course is tailored to extensive instrument training. The tactical airlift course will use the fidelity of the new C-130 operational flight trainer (OFT) to train station keeping and airdrop procedures. The training potential of the single C-130 weapon system trainer (WST) is currently being explored to provide visual formation, low level navigation and visual airdrop training.

In the mid 70's, MAC decided that some maneuvers performed in the simulator could be substituted for aircraft required currency events. A subjective certification of each device was conducted. It was determined that aircraft required approaches could be replaced by instrument approaches performed in the simulator. During this same time period, credit was given for all simulator time logged in computing upgrade requirements.

SIMCERT

In the mid 70's, Congress, through the Air Staff, directed that each command establish a program to insure that training devices being procured were used effectively. The Air Force simulator certification (SIMCERT) program was established to implement this directive. The purpose of the SIMCERT program is to ensure that:

a. The training capability of each aircrew training device is defined in order to be effectively integrated into the proper aircrew training program.

b. All ATDs receive update modifications as required.

c. All ATDs continually perform according to set standards.(5)

The MAC SIMCERT program meets the stated criteria by conducting annual certification testing of each ATD. This testing uses the contractor developed acceptance test procedure as its baseline. In addition to testing the ATD, the SIMCERT team also evaluates the training courseware to insure the capabilities of the training device are being effectively used. As new equipment is installed on the aircraft, the SIMCERT team evaluates the training requirement and recommends modification requirements for the ATDs.

A SIMCERT team has been established for C-130 ATDs at Little Rock AFB, Arkansas. The C-5 and C-141 SIMCERT team is located at Altus AFB, Oklahoma. Each team is composed of aircrew instructors and maintenance personnel. In addition to their other duties, the SIMCERT team is the command's design team for acquisition, modification, development, and design reviews. This approach includes the users in the design process at an early stage so that they may help identify or further define the users' training requirements. Another benefit could be the early identification of trainer deficiencies and to provide user interface when program or scope changes are anticipated.

Simulation Training Studies

There are several ongoing studies being conducted on MAC simulators. A transfer of training study is attempting to determine the value of the C-130 General Electric visual system for low level navigation and tactical training. A performance measurement system is being installed on the C-5 simulators at Altus to determine its usefulness to the instructors. A proposed study of skills maintenance is of vital concern to MAC. As an interim measure, MAC is developing a study to determine the effectiveness of the Air Refueling part task trainer and its skills maintenance potential.

BENEFITS OF SIMULATION

Through the years, MAC has greatly benefited from simulation in aircrew training. The major benefit derived is increased proficiency of crew members. They are able to develop and practice their cockpit management skills when placed in a task loaded situation. They have gained increased systems knowledge and the simulation allows the crews to better understand the aircraft's limitations and evaluate mission capabilities in a degraded mode of operation. The capability to control the aircraft systems, environmental conditions, aircraft location and other traffic has greatly enhanced the probability of MAC aircrews adapting to an unusual or challenging situation.

A second benefit of simulation is the ability to reallocate the training or mission resources. Using simulators to perform tasks that are time consuming, require extensive preparation or specific resources allows valuable flying time to be reallocated. This time can then be used to conduct additional training or satisfy mission requirements.

A third benefit is that of flight safety. There are numerous risky maneuvers that are performed in training that place the aircraft near the edge of its performance envelope. Using the simulator to initially train and practice these maneuvers on a routine basis will reduce the risk to a crew and their aircraft. By using the simulator, the conditions can be controlled, the student receives practice and can be evaluated at no risk to those involved.

Another benefit of simulation is flying hour avoidance. Although secondary in importance, it's often viewed as the primary benefit by many, especially in today's economy. Simulation can save valuable aircraft hours, fuel, and operating costs. In 1983 MAC estimates that the following additional hours would be required to maintain the same level of aircrew proficiency if simulation were not available:

C-5	9428	hours
C-141	24356	hours
C-130	1913	hours
HH-53	714	hours
CH-3	1087	hours
C-135	276	hours
Total	37774	hours

These hours represent approximately 70 million gallons of jet fuel. The total dollar savings would be approximately $293 million.

When all C-130 OFTs are fully operational we estimate an additional flying hour avoidance of 6385 hours. This will save 4.8 million gallons of jet fuel and a total of approximately $11.1 million per year.

In terms of the learning process, simulation has many benefits. The benefits described above are the primary benefits to MAC. The overall bottom line is that simulation allows MAC to provide highly qualified crew members trained to perform the MAC mission.

FUTURE PROGRAMS

MAC's goal is to develop a total instructional system that will provide aircrew personnel a continuum of training from entry into the career field through to a fully qualified instructor status. In the future, crew members should find a well rounded, complementary program in the initial, continuation and upgrade training programs. Most training items will be thoroughly learned on the ground and validated in the aircraft. The training system should include learning centers, an effective family of aircrew training devices, and aircraft.

To meet this goal, future aircrew training device acquisitions will follow the philosophy of acquiring a family of training devices to allow training in a "building block" fashion.

The newest program is the acquisition of seven C-5/C-141 air refueling part-task trainers (ARPTT). The ARPTT will be a generic cockpit to train the pilots in air refueling. The specific task will be from the pre-contact (approximately 500 feet behind the tanker) position through hook-up and disconnect from the tanker. This system must include a wide field-of-view, high fidelity visual system. The trainer will be used for both initial crew qualification and refresher training for qualified crews. An ARPTT that meets MAC's requirements has the potential for great savings and improvements in aircrew training. The savings are associated with the goal of an all air refueling force and its related training requirements. There is an insufficient number of tankers to support the currency requirements and by using the ARPTT, MAC will be able to maintain a fully qualified air refueling force.

Both the H-60 helicopter program and the next transport program have requirements for a family of training devices: procedure trainers, operational flight trainers (simulator without visual) and weapon system trainers (full mission simulator with visual).

MAC also has plans to refurbish the existing C-5 flight simulators in conjunction with the procurement of the C-5B ATD's. Currently, the C-141 and C-135 simulators are on contract for complete refurbishment. These programs should produce trainers that will be logistically supportable for years to come.

The Command is also determining the usefulness of Special Function Part Task Trainers to train and update aircrew's knowledge and proficiency levels. These are interactive computer based training systems that can be used to simulate new aircraft hardware or equipment modifications. In addition, the systems can be used for student management, administrative support and data gathering.

Line-oriented flight training (LOFT), used by many airlines, can be very beneficial to our training system. MAC's programs have always been based upon a realistic mission profile but they continue to be very task saturated. The proficiency programs are being revised to incorporate the LOFT concept. The missions will be structured to require the aircrew to make decisions and take appropriate actions based upon mission requirements, aircraft operations and existing conditions. The instructors will control the conditions, monitor progress and evaluate the training needs of the students. Instructors normally hold their comments and critiques till the mission debriefing. Additionally, we envision more specialized training for each crew position tailored to the individual's experience.

The future of simulation in the MAC programs is bright. Plans are to continue the use of simulation with an increased emphasis on individualized training.

PROBLEMS

MAC's aircrew training device programs are not without problems. Some of these problems have been in the command since 1953, and solutions still are not readily available.

The major problem facing the day-to-day training operation is inadequate manpower. Although increased instructor authorizations have been identified as a valid requirement, funding for these authorizations has not been approved. This requires the use of "on-loan" instructors from airlift squadrons to fill the shortfall, which is detrimental to the squadron's training program.

The lengthy acquisition process for new training devices presents a second problem. Training requirements are identified, evaluated and needs are established through Air Force channels. Ten years may pass before the device actually arrives. A prime example of this is the new C-130 flight simulator. The original requirement was written in 1971. The acceptance of the first of 10 devices was in 1981.

The problem also exists when modifying or upgrading training devices. Some progress has been made towards resolving this lengthy procedure. In the past the simulator configuration lagged that of the actual aircraft. Changes in Air Force regulations and improvements within the Ogden Air Logistics Center (simulator depot) and MAC have brought the simulator configuration closer to that of the aircraft. Experience indicates that close cooperation between the user (MAC) and the depot (Ogden) significantly reduces this problem.

Defining user requirements in terms understandable to the acquisition agency has long been a problem. The translation of user requirements into an engineering specification produces varied results. As far back as 1953 when MATS was attempting to acquire a C-118 flight simulator, "certain differences of opinion" between MATS and the Air Research and Development Command occurred.(6) The same is true today. A better means of communication still needs to be devised.

Problems also occur after a contract is awarded for a new device. As the design progresses, certain tradeoffs must be made. Many factors affect these tradeoff decisions. Often neither the user nor the acquisition agency is involved until the decisions are final. This often results in schedule slips, cost overruns, or decreased capability. The user must wait until the device has completed acceptance testing before he can develop a training program utilizing the device's capabilities. The continuing uncertainty of delivery dates and training capabilities continue to be of concern to MAC.

CONCLUSION

The Military Airlift Command is proud of its aircrew training programs. By effectively using a family of ATDs, simulation has proved to be a most effective training tool. With it, MAC is able to produce quality aircrew members beginning with the initial qualification programs and then maintaining their readiness in the operational environment. Simulation greatly enhances this capability and results in significant savings to the Air Force. Heretofore, MAC has not had adequate ATDs to train such tasks as air refueling, instrument and visual formation, tactical low level navigation, airdrop and assault operations. The anticipated advances in technology and the continued use of simulation with an increased emphasis on individualized training will allow MAC to effectively train these and other tasks.

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VTXTS - A COOPERATIVE EFFORT BETWEEN THE USER, THE CHIEF OF NAVAL AIR TRAINING, AND THE CONTRACTOR- MCDONNELL DOUGLAS CORPORATION

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ABSTRACT

VTXTS is the totally integrated training system designed to satisfy the U.S. Navy's Undergraduate Jet Flight Training requirements for the 1990s and beyond. The acquisition of the VTXTS to replace the current Intermediate and Advanced Strike Flight Training programs of the Naval Air Training Command will climax several years of intense effort on the part of the Naval Air Systems Commands, McDonnell Douglas Corporation and the ultimate user, the Naval Air Training Command. VTXTS is one of the first major defense acquisitions wherein the entire training system is being designed, developed and produced by a single contractor. This process is affording the Navy the opportunity to explore innovative ideas and advances in technology in all areas of the training system.

In this paper we will demonstrate how the operational and instructional inputs by the Chief of Naval Education and Training (CNET) and its major functional command, the Chief of Naval Air Training (CNATRA), have been and will continue to be significant factors in ensuring that VTXTS will be responsive to the needs of the Navy for a state-of-the-art jet training system through the next twenty years.

BACKGROUND

The Naval Air Training Command has been training highly skilled and qualified aviators for the fleet for decades. In recent years the flying skills and tactical knowledge required of the newly designated aviator as he moves to his fleet assignment have advanced to a level undreamed of in years past. The unique and demanding requirements of carrier aviation have always been reflected in the training methodologies of the Naval Air Training Command, and the training system has continually been revised and updated to reflect the current fleet needs. The structure of the Navy's Undergraduate Pilot Training Program has also changed to meet the current needs of each era. The Naval Air Training Command utilizes separate training "pipelines" for different aircraft missions. With this pipeline concept, separate training systems are established for three general aircraft mission types: tactical or strike aircraft, multiengine aircraft and helicopters.

Student Naval Aviators (SNA) for the Navy, Marines and the Coast Guard enter the Naval Air Training Command from a variety of sources including the U.S. Naval Academy, The Coast Guard Academy, College ROTC programs and both Navy and Marine Corps Officer Candidate Schools. They are trained within the Naval Integrated Flight Training System (NIFTS) which begins for all students with Preflight at the Naval Aviation Schools Command in Pensacola, Florida. After Preflight the Student Naval Aviators begin their flight training in a common Primary phase flying the T-34C aircraft. At the completion of Primary flight training, students are selected for one of three Intermediate training pipelines, strike, maritime (multi-engine) or helicopter. Students in the strike pipeline fly the North American T-2C twin engine jet for Intermediate phase and the McDonnell Douglas TA-4J for Advanced. The VTXTS will replace these two aircraft with a single aircraft and a totally integrated training system for the strike pipeline.

CONCEPT

VTXTS is a total training system, composed of a jet trainer aircraft, a suite of simulators, academics, and a computerized training management system. These four elements are integrated into mutually supportive building blocks which enable the Student Naval Aviator to meet the training requirements in the most effective and efficient manner. The VTX training system is the functional integration of these building blocks within a working process. This integration is shown schematically in Figure 1. The ongoing evaluation and coordination of this functional integration by CNET as well as by CNATRA will ensure that the final product of this system, the designated Naval Aviator, will meet the needs of the fleet. It will also ensure that fleet feedback is promptly evaluated and appropriate revisions to the training system are effected. VTXTS is one of the first major defense acquisitions wherein the entire training system is being designed, developed and produced by a single contractor and procured by the Navy as a fully integrated system and program package. This process is affording the Navy the opportunity to explore innovative ideas and advances in technology in all the elements of the training system, not just in the area of aircraft design. The acquisition process is also providing an exceptional opportunity for the immediate using command, CNATRA, to provide continual and ongoing inputs throughout the design and development cycles. The fact that the end product of this acquisition is a training system, not a weapons system, has facilitated the exploration of new and innovative ideas in training equipment, methodologies, and advanced training technologies. A key task of the prime contractor is to include the operational inputs of the using command in the integrated design engineering development process. The end objective is a working system that provides the required training levels and rates over a 20 year program at the lowest cost to train.

Any discussion of user input to the VTXTS should include a description of the relationship between CNET and CNATRA. Since 1972 CNET has been responsible for all formal Navy training. CNATRA is one of several functional commands under CNET and draws on the assets of the CNET staff for many areas of technical and training support. Some of CNET's other functional subordinates include the Naval Training Equipment Center (NTEC), the Navy Recruit Training Command, the Chief of Naval Technical Training (CNATECHTRA) and the NROTC Command.

The formulation of the VTXTS concept began in the mid-1970s when CNET directed CNATRA to conduct the initial Undergraduate Pilot Training (UPT) Task Analysis. The purpose of that UPT Task Analysis was two-fold: first, to verify the existing training procedures and curricula, and identify any deficiencies, and second, to apply these findings to the training program in achieving the required modifications and improvements. The results of this task analysis were published in the Phase I and Phase II Task Analysis Reports. This UPT Task Analysis initiated the participation of the CNATRA staff in the acquisition process for the VTXTS. It has been this participation at each step in the conceptualization and design process that will help to ensure that the VTXTS will meet the needs of the using commands.

The thread of CNATRA's active participation in the VTXTS process continued when the Chief of Naval Operations (CNO) requested industry participation in conceptual design studies of an Advanced Navy Jet Trainer. A competitive solicitation was conducted to obtain ideas, approaches and conceptual designs for this aircraft. The Naval Air Development Center (NADC) contracted with four aircraft manufacturers, McDonnell Douglas Corporation, General Dynamics Corporation, Northrop Corporation and Vought Corporation for the conceptual design studies. Briefings and dialogue with the four contractors established a definite need to address all elements of this total training system rather than just the aircraft. Both CNET and CNATRA had been very active in the early efforts leading up to these studies. In addition to the UPT Task Analyses that CNATRA had conducted, the Naval Training Equipment Center had completed the Training Situation Analysis (TSA) specifically for the VTXTS, in which various training media required for a state-of-the-art training system were addressed. The baseline requirements of the system used by the four contractors in their technology studies were based on discussions with the Naval Air Training Command staff and instructor pilots. VTXTS workshops were conducted at CNATRA in preparation for the technology base studies and the contractors had access to the Task Analysis Reports, the TSA and the then-current NIFTS curriculum. At the completion of these technology base studies, an analysis team was established to review and summarize the results of the studies. CNET and CNATRA were again heavily involved in the review process. Members of the CNET and CNATRA staffs, as well as Subject Matter Experts (SME's) from Training Wings Two and Three were included on the analysis/review committee. The review committee assessed the study data in various areas including methodology, concept options, effectiveness measurement and cost.

In March 1979 the Mission Element Need Statement (MENS) for the VTXTS was signed by the Secretary of Defense signalling the formal initiation of the VTXTS program. Under OMB Advisory Circular A-109, the Mission Element Need Statement formally establishes the need for the system involved and signals Department of Defense concurrence. The signing of the MENS is Milestone zero in a specified series of decisions by the Defense System Acquisition Review Council (DSARC). Following the issuance of the MENS, a Request for Quotation (RFQ) was issued for the Alternative Systems Exploration studies in December 1979. Once again, CNATRA participation in the acquisition process was evident. CNATRA assembled a team composed of CNATRA VTXTS Special Projects members, representatives of the training wing staffs and instructor pilots from the training squadrons. In conjunction with the CNET Educational Specialists, this team developed the Terminal Learning Objectives (TLO's) for the VTXTS. The 87 TLO's provided the means to define the specific goals of the VTX training system. The TLO's describe flying skills that the student pilot will be expected to demonstrate prior to the completion of the VTXTS curriculum. CNATRA staff members also provided operational inputs to the Naval Air Systems Command (NAVAIR) for the Constraints and Guidelines section of the Request for Quotation. As a result of this competitive solicitation, six contractors were awarded contracts for Alternative Systems Exploration (ASE) studies. These six-month studies enabled the contractors to complete in-depth analyses and trade studies on the varied aspects of the training system requirements. Within the limitations of the MENS, the RFQ Constraints and Guidelines, and the TLO's, each contractor was able to propose its own training system including recommendations for the allocation and arrangement of the system elements.

As the acquisition process was originally established under the provisions of OMB Advisory Circular A-109, The Naval Air Systems Command was to evaluate the ASE studies and select one or more contractors for continuation into the following acquisition phase, Demonstration/Validation (DEM/VAL). The DEM/VAL phase was to be a risk reduction process in which the contractor would develop selected portions of the proposed training system for demonstration and validation of the concept. In November 1981 the McDonnell Douglas/British Aerospace proposal was chosen in the source selection as the winning entry. With the narrowing of the selection process to a single contractor team, the concept of a DEM/VAL phase has changed to a Pre-Full Scale Development phase, Pre-FSD. The Pre-FSD phase will be followed by the Full-Scale Development and ultimately the Production phase of the VTXTS acquisition. As the VTXTS acquisition process continues, a cooperative working relationship will be established between the contractor, McDonnell Douglas Corporation, and the using commands, CNET and CNATRA. The beginnings of this working relationship that have evolved after the source selection are helping to ensure adequate user input to the training system in its design phase. In the future, the benefits of this early user input to the development process will be even greater. By the early integration of the end user's requirements into the training system development process, the resultant system will reflect more accurately the real needs and requirements of the users.

PROJECTIONS

Early in the VTXTS acquisition cycle, CNATRA, as the primary using command, established a VTXTS Special Project team. This group is composed of CNATRA staff personnel with extensive backgrounds in all areas of the Naval Air Training Command operations including flight operations, simulator instruction, academics, maintenance, facilities management and general military training. The experience of this group, coupled with CNET's staff of instructional technologists, enabled the using commands directly involved with the VTXTS to provide the operational input that is so vital to the acquisition of a totally integrated system

McDonnell Douglas Training Systems Engineers recognize the importance of this operational expertise to the success of the VTXTS. The timely and proper utilization of that expertise as the system acquisition progresses will be a key factor in ensuring that the VTX training system will be responsive to the real world needs of the training command users in the late 1980's beyond.

CNET/CNATRA input to the development process is expected to be especially valuable in the areas of curriculum outline refinement, final definition of the simulator functional equirements and operational inputs to the raining Management System (TMS). The final integrated academic, simulator and flight curriculum will be a reflection of the total VTX system concept. It is essential that the ever-changing operational requirements as identified by CNATRA staff as well as training wing and training squadron personnel be integrated into the VTXTS curriculum to ensure that it is both operationally and instructionally sound. The Training Management System (TMS) represents another area where the user input will be especially important. In the current NIFTS the individual squadron's schedules officer is a key to the successful flow of students through the curriculum. The schedules officer assembles information on student and instructor availability, aircraft availability academic and simulator requirements, and a myriad of scheduling directives into a daily flight schedule. The operational expertise of key personnel such as these schedules officers will be vital to the implementation of the Training Management System into the training command structure.

CONCLUSIONS

The operational environment of the Naval Air Training Command is unique and demanding. It is one of the best military pilot training programs in the world. It is dynamic and ever-changing in response to the needs of the fleet. The fact that the Naval Air Training Command has maintained this pre-eminent position is a tribute to the CNATRA staff, the Training Wing staffs, the training squadron personnel and the support personnel at the training bases. The challenges presented to the prime contractor, McDonnell Douglas, in developing the VTXTS, integrating the elements of the system and implementing the system into the Naval Air Training Command are indeed formidable. The task will require a closely coordinated effort between the contractor and the using command for identification of real-time operational requirements and the integration of those requirements into the training system. The ground work for this close cooperation between user and contractor has been laid. As the development effort moves ahead during the FSD phase, this ground work will form the basis for a cooperative working relationship between user and contractor that is vital to the ultimate success of the training system. To date all contacts between contractor and user have been closely coordinated and controlled by the VTXTS acquisition manager, the Naval Air Systems Command. NAVAIR will continue to function in this important position as coordinator between user and contractor.

The entire VTXTS concept of a total training system with all of its elements--aircraft, simulators, academics and training management system, designed and developed by a single contractor-- is new. The challenges facing the training command today are also new and ever-changing. The cost of training resources has risen dramatically and the continued availability of current assets has become difficult to maintain. VTXTS will enable the Navy to reduce the cost to train each student by providing a fuel-efficient training aircraft, improved simulator capability, an interactive computer-assisted academic system and an automated training management system. The ever-rising cost of fuel is a significant factor in the total cost to train. The new VTX aircraft with its fuel-efficient engine and its increased reliability over the current strike pipeline aircraft will provide a major reduction in training costs. The state-of-the-art VTXTS simulator suite and the interactive Computer Assisted Instruction (CAI) system allow the number of required flight hours to be reduced substantially, providing yet another major cost reduction. Many of the peripheral administrative demands placed on flight instructors by the current NIFTS will be automated in VTXTS by the Training Management System. Instructors, relieved of many of those administrative, bookkeeping ype responsibilities, will have more producti·· time available for actual direct instructor to student interface within the instructional environment, ensuring an even more well-trained Naval Aviator than ever before. The level of sophistication and advanced technology in the Navy's modern fleet aircraft requires ever-increasing flying skills and systems management skills on the part of the newly designated Naval Aviator. VTXTS will provide him with basis of those skills.

The need for VTXTS is clear, and the need for close integration of the CNET and CNATRA experience in training command operations with the broad base of McDonnell Douglas expertise in aircraft and systems engineering is equally evident. It will be the cooperative working relationship between user and contractor which will result in the development of a viable training system capable of producing quality Naval Aviators for the fleet at a lower cost-to-train than ever before. The VTXTS will meet the Navy's need for a quality training system in the Naval Air Training Command. The VTXTS trained Naval Aviator will be even more well prepared to transition to the fleet aircraft of the next two decades than his predecessors were. He will be ready to meet the challenges and rewards of a career in carrier aviation with the United States Navy.

ABOUT THE AUTHORS

Mr. Schuck is a Training Systems Analyst at Douglas Aircraft Company in Long Beach, California. He is currently involved in ISD and curriculum development efforts for the VTXTS. He previously participated in the development and implementation of courseware for the U.S. Navy's F-14. Mr. Schuck is a former Naval Aviator whose background includes experience in U.S. Navy carrier and training command operations.

Mr. Riley is the Assistant Chief of Staff for flight training at the office of the Chief of Naval Education and Training. He has co-ordinated the implementation of the T-34C aircraft into the Primary phase of the NIFTS curriculum and the T-44 aircraft as the Advanced Training aircraft in the multiengine pipeline. He has been directly involved with the VTXTS project for the Navy's strike training pipeline since the inception of the program in the mid-1970s.

Commander Jones is currently the Chief of Naval Air Training Program Manager for VTXTS. He is directly responsible for CNATRA involvement and operational inputs for all elements of the VTXTS. Commander Jones' background includes extensive experience in Navy tactical carrier aircraft as well as the strike training pipeline of the Naval Air Training Command.

SYSTEM CONCEPT

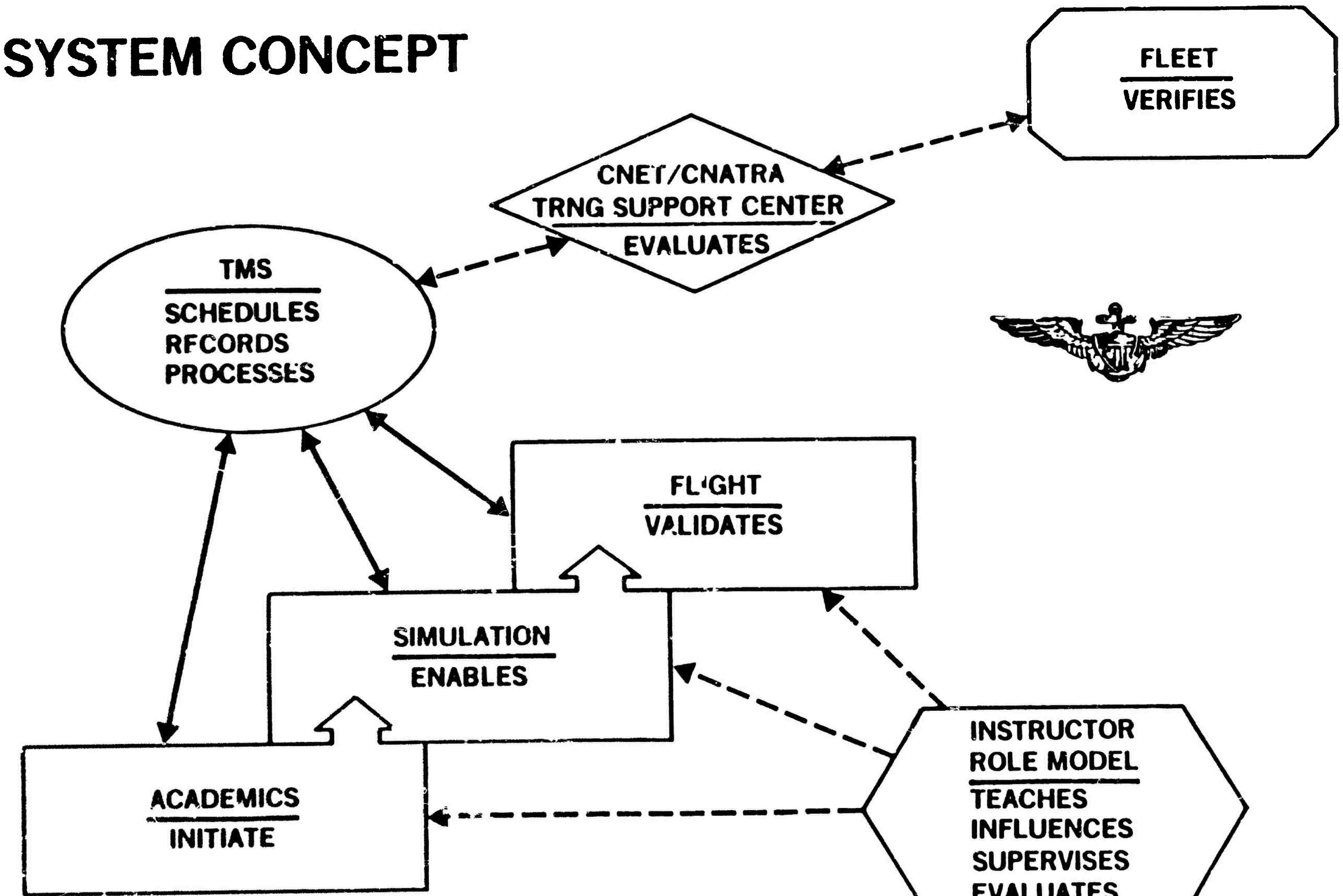

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FIGURE 1

SYSTEM CONCEPT

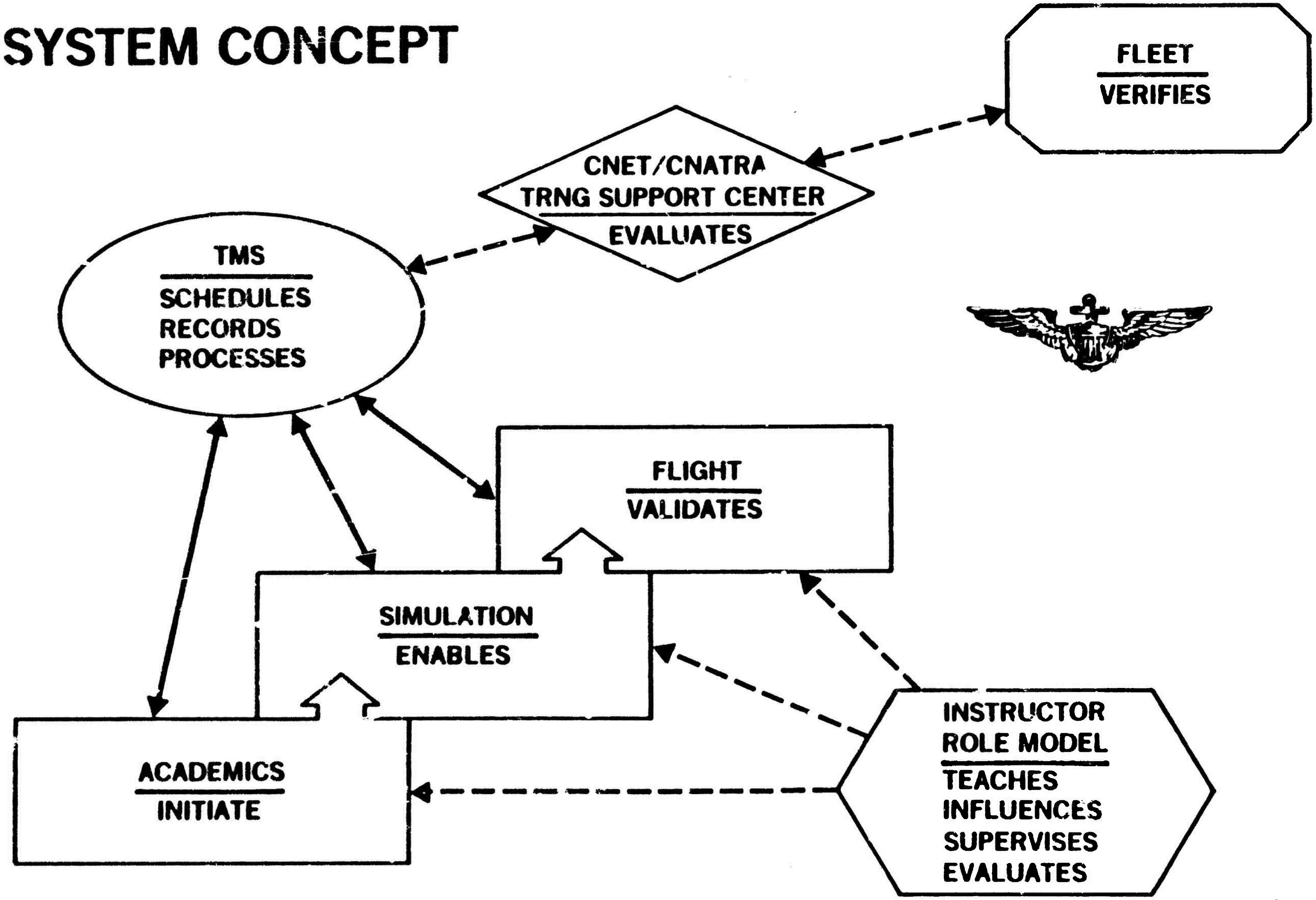

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FIGURE 1

TRAINING DEVICE SUPPORT CONCEPTS FOR THE FUTURE: A PROBLEM SOLVING APPROACH TO COST REDUCTION

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ABSTRACT

This paper addresses training device logistics support problems encountered by both the customer and the contractor. It describes specific support area problems, and secondary problems created by implementing short term solutions. Many of the problems were initially caused by a rapidly changing technology, and an environment beyond the control of the concerned parties. As the paper traces through attempted solutions, it endeavors to extrapolate past and present efforts into a projected support concept for the future.

INTRODUCTION

Over the past thirty years, the armed forces of the United States of America have made great strides in the development of new and unique weapons systems. With the advent of space age technology, these systems have become more complex with future growth potentials that are virtually unlimited. Along with this trend, the costs associated with owning and operating these systems has increased enormously. Training of operator and support personnel has become a major problem, and logistics support concepts have become as complicated, and as expensive as the systems themselves. The high cost of operating these systems has made their use for training purposes cost-prohibitive. As an alternative, the use of training devices to conduct training has become even more cost effective when compared to conducting training on the actual operational system. Continuing as a natural outgrowth of this trend and spurred on by the rapid advances in state of the art technology, there has been an impetus to incorporate increasing realism into the training device, producing simulators that closely replicate the operational system and its environment. Consequently, the simulation device becomes not only a complex procurement exercise but also a major support problem. The scope of the problem, and the costs involved, are second only to those encountered in supporting the operational system.

To keep pace with the increasing complexity, full scale logistics support programs have been developed to meet the customers' requirements. As the logistics base has expanded to meet the unique support requirements of each customer, the costs of simulators, including design documentation, training, spares support, test equipment and maintenance data have increased. In attempting to minimize acquisition costs and meet production schedules, the trends exhibited by both contractor and customer have been concentrated toward increased simulation capability, placing logistics support secondary. This situation is not unique to the training device community.

Recognizing the evolutionary process that weapon systems have undergone over the past thirty years, this paper endeavors to provide a few observations on the corresponding evolution of training devices, and training device support concepts. These observations become apparent when the major problem areas, both past and present, are examined and how the attempts at solving these problems have influenced current support concepts. It is axiomatic that the solutions implemented to solve today's problems will dictate the support concepts of the future.

The paper draws upon the experiences of the authors primarily in the areas of aircraft simulation programs for the military. The application of statements made and conclusions drawn to other types of training devices similar in complexity, are considered valid.

CURRENT MAJOR PROBLEM AREAS

It is obvious that an attempt to analyze all the problems concerning the logistics support of training devices would require an in-depth study and would result in volumes of data. This paper identifies some of the current major problem areas and describes them without attempting to sequentially rank them in order of importance. These problem areas are all inter-related and are generally driven by the acquisition process. Several areas noted in the paper were addressed in-depth in last years proceedings. Each discussion will encompass the problem, related cost impacts, past solutions, and anticipated current results. The problem areas selected for discussion will be addressed individually, and are as follows:

- Device Sophistication
- Commercial Off-The-Shelf Equipment
- Reliability, Maintainability and Availability
- Spares Support
- The Changing Maintenance Concept
- Personnel and Training
- Data

Device Sophistication

The training device has evolved from a rudimentary training aid to be used in perfecting procedures and maintaining basic proficiency to a complex, highly versatile piece of hardware that is capable of providing detailed operational and tactics training in various programmable real world scenarios.

As aircraft and tactics become more sophisticated, they dictate even more sophisticated training devices for the various armed services. In doing so, they frequently advance state-of-the-art. In the case of flight simulators, the device must duplicate the interior cockpit section in appearance and provide specified performance characteristics identical to that of the actual aircraft. In addition, the device must be capable of simulating the multi-mission training scenarios required by the military.

To achieve a simulation design that faithfully reproduces the operational aircraft and provides for an effective training system, the first task encountered is to clearly specify the extent of simulation required and the training requirements or goals, i.e., customer's planned utilization of the device as an instructional system. These tasks should receive maximum effort and should be definable given that the operational system has achieved a reasonable level of design maturity. The second task requires the contractor to accurately interpret those requirements. Not withstanding the technical and training aspects of simulator design, the maintenance or logistics support concept must also be clearly stated by the customer to the extent necessary, and interpreted accurately by the contractor. Obviously, close liaison between customer and contractor is required throughout the program's life cycle.

The increased sophistication and requirements for multiple training scenarios are driving the need for large capacity, high speed computer systems. This in turn requires the development of high speed data interfaces to provide the real time simulation required to achieve the realism desired. Computer systems as well as many of the high speed data interfaces, are of a commercial nature. Also considered as commercial hardware (catalogued-items) for purposes of this example, are visual and graphic display systems and peripheral hardware to the computer system such as line printers, CRTs, disc and magnetic tape equipment. Thus, to meet design and delivery criteria, an ever increasing amount of off-the-shelf equipment is included in the design. From a parts count viewpoint, 60-70 percent of the simulation hardware is resident within the commercial systems.

Commercial Off-The-Shelf Equipment

The use of commercial off-the-shelf equipment items in the manufacture of training devices has become common-practice in the training device industry. This practice evolved as a result of efforts by both government and industry to minimize acquisition costs, and provide realistic and obtainable delivery schedules in response to the terms and conditions of government contracts. A positive outcome of this was, and continues to be, the development of a market place for various commercial systems.

Usually, commercially available high speed computer systems comprise the heart of a training device. Further, these systems many times are state-of-the-art. The reasons for this approach are quite evident: first, there are no MIL-STD computer systems available that meet the demanding simulation requirements. Development of a MIL-STD system would be cost-prohibitive. Additionally, the government procurement process being what it is, state-of-the-art advances might well make the system obsolete prior to it becoming operational. Secondly, significant cost reductions are realized as R&D costs for commercial computer systems are shared by all users. Without the lengthy R&D process, it is much easier for training device manufacturers to meet required device delivery schedules. Finally, the use of commercially available computer systems eliminates some of the unknown factors associated with R&D. Reliability and maintainability characteristics many times have been proven through demonstration or field results. Quite often, the selected system is already integrated into current customer inventories which reduces the scope of the logistics support problem. The bottom line is that the training device environment, especially in flight simulators, is basically benign and a MIL-STD computer is not required.

At first glance, it appears that significant cost reductions are realized through the use of off-the-shelf computer systems. In most cases, this approach is used advantageously. There are, however, some risks associated with this method. Generally, a commercial computer manufacturer will produce a specific model line for a limited period of time. He cannot afford to exclusively cater to the training device industry because the market is too small. He must produce for the commercial market. To remain competitive in the market place, he must keep abreast with changing technology. With the advent of subminiaturization of components, improved packaging techniques, and the wide availability of low cost memory modules, the commercial computer industry is growing at an unprecedented rate. The life span of a product line seldom exceeds five years. By contrast, the programmed life span of a training device is seldom under 20 years. Similarly with the comments made about MIL-STD computers, the time elapsed before the government procurement process places a system in the field causes the commercial system to be potentially obsolete. This is generally true with any government procurement. One major problem is that training devices are not procured in quantities comparable to other military hardware. Therefore, logistics support of spare parts manufactured by commercial vendors is not likely to remain viable over the programmed life span of the training device. Obtaining guarantees from vendors to assure supportability and configuration control over the trainer's life cycle may be cost prohibitive or impossible to obtain. Many manufacturers do, however, provide "downward compatibility" of parts for superceded systems. There is some risk here in maintaining both in hardware and software, the total integrity of the original system.

In terms of operating hours and trainer sortie rates, utilization of training devices far exceed that of the operational aircraft. Although the environment is totally different, complexity of aircraft training devices approaches and often exceeds that of the aircraft. Obviously, the logistics support concept for a training device must be approached with a perspective different from that of a major operational system. An aircraft manufacturer, or any manufacturer with large quantities of equipment in the field, must provide a support capability for that equipment.

Similarly, a training device manufacturer must also provide support. The vendors he buys from are not so obligated. With current trends towards depot level maintenance for computer components, the vendor in many cases becomes the depot level repair or exchange facility. Equipment turn-around times and replenishment spares become a problem that increases in direct proportion to the life-span of the device. In many cases, the only apparent solution to the problem is a costly computer update to the existing training device, because the original computer has become increasingly unsupportable. Specifications can be written to eliminate all but a particular vendor without actually referring to a product line. This is done because of customer satisfaction with a particular product or in an attempt to use spares and other support assets that may already be in his inventory. A potential pitfall here is that vendors, in providing the depot level repair or exchange service, tend to update their components to the latest design revision level. The part number of the component remains essentially the same however, the customer cannot differentiate between revision levels. Consequently, the component may or may not be fully interchangeable with the systems in the field and the customer may have unknowingly degraded his support capability.

Perhaps the most significant drawback resulting from the use of commercial computer systems is that the training device industry cannot place a direct demand on computer manufacturers to ensure that their products will continue to meet the requirements for sophisticated simulation. The potential problems of off-the-shelf computers may be analogous to problems of supporting older tube-type electronic systems.

The customer may, at some point in time, have to pay the price to bridge the technology gap. Reference can be made to those draft specifications circulated for industry review and comment where the customer is told by industry: "we cannot get there from here with today's state-of-the-art." Attempts to bridge the state-of-the-art gap may result in excessive expenditure of R&D funds with the potential for poor equipment performance in the field in that the hardware has unknown and unproven reliability characteristics. This impacts not only the operational aspects but supportability as well.

Reliability, Maintainability and Availability

In general, most contracts call out Reliability and Maintainability plans and demonstrations to prescribed levels of performance. The customer apparently has two distinct concerns. First, from the operations standpoint, he is concerned with equipment or system availability, and does not care about the combination of MTBF and MTTR required to achieve that level of availability. Secondly, he is concerned with the cost of supporting the item. From the second concern stems the rigid reliability and maintainability requirements. As graphically shown in Figure 1, once the MTTR is under five hours with an MTBF above one hundred hours, increases in MTBF add little increase in marginal availability. Thus, in respect to inherent availability, the efforts in reliability are misdirected.

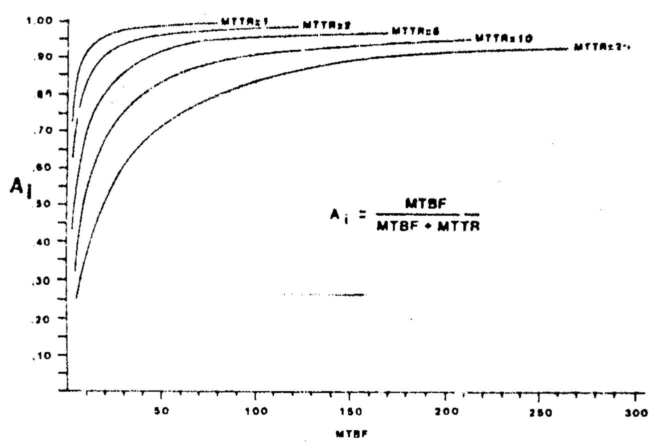

Figure 1

Up to this point a theoretical inherent availability has been described, but the actual concern should be with achieved availability. The elements of supply times, operator and maintenance induced failures, and preventive maintenance times must be added to the downtime portion of the equation. From the operators position, the downtime caused by scheduled maintenance, operator induced failures, and downtime caused by nonresponsive supply systems must be reduced. These causes for downtime produce a far greater loss of availability than the inherent failures.

Logisticians and support personnel should be less concerned with inherent system reliability, and focus their attention on the areas of supply support, scheduled maintenance, and the inherent reliability of high cost or scarce components. System failure data provided in accordance with MIL-STD 785 has little or no relationship to achieved availability nor to cost of supporting a system. More attention, therefore, must be placed upon high cost or scarce components during early design reviews. This is where reliability efforts pay off.

Spares Support

With availability in mind, rapid repair of the simulation device has been driven to remove and replace at the organizational level. This repair is limited to the removal and replacement of parts and minor overhaul of nonelectronic parts. Maintenance at the intermediate level has diminished because most multi-layered PCBs are routed to a military supply depot for repair or disposition. Many of these boards are then routed to a special repair activity, normally a contractor or vendor plant. The boards are then repaired and returned through the same channels. This circuitous routing may consume many months. This lengthy process is expensive in both administrative handling and in terms of additional spares to fill the pipeline. It is a generally accepted fact that pipelines have a habit of "eating" spares.

In many simulator programs the government and contractors have reduced the pipeline time by direct contractor or vendor support programs of spares. On Navy programs, Repair of Repairable contracts are established during the interim support and follow-on phases to expedite site-to-vendor repairs.

This is an approach to support which reduces cost, increases device availability, and increases overall performance. It should be realized however, that this procedure further degrades government organic support capabilities even though costs may be the overriding factor.

What is observed in these types of procedures is a defacto change in the maintenance concept. A formal recognition of this change must be considered during the provisioning phase of the acquisition process, due to the increased pipeline turnaround times. A broader acknowledgement and appreciation of the actual maintenance concept should begin a process in achievement of cost-effective approaches to training device support.

The Changing Maintenance Concept

Today as in the past, systems are being designed for maximum self sufficiency at the base level with increased emphasis on the organizational level of maintenance. The extensive use of Built-in-Test (BIT), Built-in-Test-Equipment (BITE), daily readiness checks and demonstrations and associated diagnostic routines have enabled the organizational level technician to fault isolate to a much lower level than in the past. Equipment is being designed for ease of maintenance with modularity in mind to enhance repair times and optimize device availability.

Historically, the armed services have employed a three level maintenance concept: organizational, intermediate and depot. The organizational level has generally consisted of removal and replacement of major components "on-equipment" with some bit/piece-part repair when applicable. The major purpose being to return the end item to an operational condition in a minimum amount of time. The intermediate level has consisted of "off-equipment" repairs (to those major components removed at the "O" level) using the same remove and replace theory at the modular level. The main purpose here is to return a serviceable major component back into the supply system to support the "O" level of maintenance. The depot level has included those repair capabilities at both "O" and "I" level with the additional capability to perform major equipment overhaul. The intent being to perform those repairs or major overhauls that are extensive, time consuming and/or exceed "O" or "I" level capabilities.

Although the basic concepts have remained the same over the years, device sophistication, technology and a quest for device availability have dictated procedural changes for the maintenance of certain types of equipment. These changes have altered the basic maintenance concepts.

One change, and probably most significant, has been the trend to relegate the repair of high technology printed circuit boards to the depot level of maintenance. The reasons for this move are many and will not be discussed in detail. However, cost is a major contributor when examined from the standpoint of the additional systems, personnel and training required to provide this repair capability for intermediate level maintenance at multiple locations. The impact when applied to the maintenance of flight simulators has been significant. In maintaining flight simulators, unlike the aircraft, PCB's are generally replaced on equipment at the "O" level of maintenance. As stated previously, a large percentage of a flight simulator is high technology commercial equipment and the respective PCB's are generally returned to the depot for repair. As a result, the intermediate level maintenance function has become less effective in that it does not produce a serviceable component to support the "O" level maintenance of high technology equipment items.

This fact must be recognized by the customer when he drafts his specifications and data requirements prior to advertising for proposals. He has recognized this situation in the personnel and training area, and has implemented programs to address it. He must also address this situation during the acquisition process.

Personnel and Training

The end of the military draft system has compounded the logistics support problem. Coupled with a shrinking pool of potential recruits, it becomes increasingly difficult for the military to fulfill enlistment quotas. The current recession and high unemployment have provided some temporary relief, but the problem still exists. Under the present system, the manpower situation cannot be expected to improve in the future, due to the demographics of the situation. Perhaps the most painful point to make is that, in most cases, the military recruits and trains a technician and industry induces him to separate after his first term of service. The proliferation of home computers, video games, video recorders, and other electronic products will also compete for services of the trained technician. The customer finds it difficult to maintain organically, all of the sophisticated hardware procured.

To further aggravate the situation, many career military personnel have dual skill qualifications. As the simulator technician alternates between jobs, his level of proficiency is somewhat degraded, depending on the length of time he is away from the training device environment. A case in point is the recent decision by the Navy making simulator technicians (TD rating) eligible for sea duty.

There are no immediate answers to these problems. Assuming solutions were available and implemented today, it would be some time before the benefits could be realized. The military personnel problem is certainly not a new one. It has been recognized in the past, and a number of measures have been implemented to correct it. This paper does not intend to discuss the success of these measures; it only points out that the problem exists, and that it has an impact on providing the required logistics support for training devices.

The second part of the personnel problem is training. Some assumptions can be made based on observations. The military approach to training is to ensure that those trained personnel will remain in the military for a sufficient length of time to provide a return on the training investment. In the past, the military provided in-depth training in the highly technical maintenance career fields. During this time a large number of trained personnel elected to make the military a career. Over the past few years, we have observed some radical departures from this approach as addressed in The Changing Maintenance Concept.

Generally, military training programs have been reduced to the level appropriate to the remove and replace maintenance concept. This has enabled the military to train new recruits to be productive in a minimum amount of time. With this approach, lengthy training is not required. Although detailed training is certainly available, it is generally provided only to career military personnel or civilian technicians. Perhaps the most noteable observation to be made here is that the military is slowly losing or eroding one of their most valuable resources, the highly trained and skilled technician.

We know the value of training programs and that cost effective training must be commensurate with the tasks to be performed. In training devices, maintenance personnel require a level of training higher than that to satisfy a remove and replace concept only. The maintenance of training devices requires highly skilled technicians capable of troubleshooting and making repairs at both the organizational and intermediate levels of maintenance. Thus the level of training must reflect the complexity of modern simulators.

Growth in the electronics industry is approximately 17 percent per annum.(1) The demand for skilled electronic technicians by industry will aggravate the problem the military faces in retaining skilled technicians. An increasing demand for a diminishing resource is foreseeable.

Data

The data requirements contained in specifications and contracts are a major contributor to the overall acquisition cost. In many instances it may be as high as thirty percent of the total. Since training devices are typically procured in small quantities, many of the data requirements are of marginal value when measured against their cost. Since design is based upon the specification and fixed early in the program, later efforts in such trade studies as Life Cycle Cost (LCC) are for all practical purposes a paperwork exercise. The same may be said of many aspects of Logistics Support Analysis (LSA), because a very large portion of the training device consists of off-the-shelf hardware and designs are essentially fixed. However, some value of LCC and LSA can be realized through their use in the equipment selection process; greater value if significant production quantities are anticipated. With a preponderence of commercial components in a training device, any measure of system reliability becomes a meaningless goal. Reliability, maintainability and availability should be considered as an entire package in respect to the end item being procured.

The relative merit of comparing acquisition cost and O&S costs can be, and has been, disected many times through many schools of thought. This paper does not want to belabor the issue, only to describe ways in which some of these costs could be reduced. If the trend towards full contractor support continues, then some of the high cost items required by contract become non-cost effective. Mil Spec technical manuals, documentation, life cycle cost programs and programs to achieve availability have great importance if the device is to be supported totally with organic resources. If the device is being supported by a contractor, they lose much of their potential value in light of their acquisition costs.

Requests for Proposal for recent simulator acquisitions places an excessive burden on the contractors to provide a plethora of reports and data items early in the contract period. In many cases, this requirement is of marginal value, a premature requirement, or a mere "square filling" exercise.(2) To procure a cost effective flight simulator, the government must first clearly identify what is wanted, then determine how it will be supported, and finally, close cooperation must exist between the contractor and government to ensure that the product meets the requirement.

WHAT DOES IT ALL MEAN?

The problems faced in supporting a training device are analogous to the problems faced in designing the system. Each element of support may be compared to a simulation module in the trainer. Addressed in isolation, a single support area or simulation module is a relatively straight forward task. However, neither of these tasks exist in isolation; they must be made to work in harmony among themselves and with the rest of the system.

The contract specification, increasing device sophistication, use of commercial equipment, availability, personnel and training, documentation and spares have been discussed. The same problems that have challenged the logistics community for years still exist, nothing new, including the use of commercial equipment and the impacts of technological change. What is new are the changes in logistics support concepts that have occurred over the years in attempting to minimize cost and solve support problems caused by the rapid growth in technology. Both customer and contractor have been driven to investigate and implement new alternatives. In doing so, systems are being designed for maximum self-sufficiency at the base level with increased emphasis on the organizational level of maintenance. Spares are normally stored at the device site. These measures, driven by the environment, have resulted in a major change in the military's basic maintenance concept as it is applied to training devices. Technology and cost have driven the services to relegate the repair of printed circuit boards at the depot level of maintenance.

The authors realize that there are redundant statements made within and between the identified problem areas. However, it is just as difficult to address a particular support area in isolation as it is to solve overall support problems by only sub-optimizing the individual support elements. To achieve optimum results in both cost and performance, all support elements including the operational aspects must be addressed as an integrated effort.

EVOLVING SUPPORT CONCEPTS

"CONTRACTING AND ACQUISITION STRATEGY[3]
The contracting community needs to employ many different tools and techniques in acquiring items necessary for the efficient operation of our forces in both peace and war. Increased weapon system costs and prices of goods and services, requires the development of approaches which assure readiness through the most efficient methods of contracting and acquisition. Therefore, this thrust area consists of the development of new and innovative techniques for improving the overall contracting and acquisition process."
1982 Air Force Logistics Research and Studies Program.

There are several approaches to reducing the acquisition and support costs of training devices. These approaches range from a simple modification of an existing procurement practice such as a sole-source contract, to a major departure from an existing maximum self-sufficiency policy, to purchasing only the training service. This latter change in policy would rely on the contractor to build, maintain, and operate the training device. The government agency would purchase only the use of the device.

The easiest procedural change for the government to make is to add increased emphasis in tailoring its data requirements to the end item being procured. In the area of training devices, particularly flight simulators, a large portion of the customer's procurement consists of commercial equipment and GFE. With this fact in mind, it appears that some LCC studies, LSAs, and reliability requirements may be misdirected efforts. These requirements, and perhaps others, could be modified or eliminated from certain RFPs and contracts. This would simply involve the tailoring of specifications to meet the intended method of support. If the government chooses to use contract field engineering services rather than provide its own maintenance, it does not require Mil Spec maintenance data; operator or maintenance training and training data; an LSA; nor Mil Spec engineering data. This approach can provide the potential for significant savings in the overall acquisition costs.

Contract field engineering services can be carried a step further by having the contractor also provide supply support. As previously discussed, the cost of a military supply system includes more than just the administrative costs of handling and storing spare parts. It also includes the costs associated with the increased spares required for the pipeline. In training devices, this pipeline has become longer due to the decreased effectiveness of intermediate level maintenance. Although a trade study of the relative merits of contractor spares support versus government supply support has not been conducted to the knowledge of the authors, such a study would certainly yield interesting results.

The concept of contractor support is not in itself a radical departure from existing practice. The armed services have in some cases contracted for base operating support services, including janitorial services, food services, medical services, and so on. The Air Force has contractor provided primary pilot training at Williams Air Force Base, Arizona. The Air Force also has contractor support for the C-9 aircraft and the T-43 trainer. The Army has a proposal for contractor base support at Fort Eustis, Va. The Navy contracts for software support of Automatic Test Equipment. Contractor support is being employed to an ever increasing extent in the area of direct mission support.

Regardless of the level of support purchased from the contractor, the customer must identify in advance and as accurately as possible, the planned support concept prior to initiating an RFP. Obviously, there are distinct advantages to identifying this during the trainer RFP phase. There have been numerous examples where the customer has changed his planned support concept late in the program. It is realized that reasons for this change may be beyond the customer's control.

Perhaps a most drastic departure from current policy would be to buy only a service from the contractor. This service would provide trained aircrews for the customer. The contractor would manufacture, maintain, operate and retain ownership of the device.

A progressive trend towards increased contractor support has distinct advantages and disadvantages for both customer and contractor.

Some advantages to the customer would be:

- Turn key operation,
- Decreased initial development costs,
- Decreased data costs,
- Decreased manpower requirements,
- Decreased operator and maintenance training requirements,
- Decreased supply support costs,
- Increased device availability,
- Decreased O&M or R&D funding costs,
- Improved delivery schedules, and
- Options to buy.

Contractor advantages are:

- Design freedom,
- Less expensive system,
- Less restrictive data requirements,
- More stable workload,
- Flexibility, and
- Responsiveness to design changes.

As with any beneficial proposal, there are inherent risks to both the customer and the contractor. However, those risks can be minimized by including appropriate conditions in the contract.

The most obvious risks are:

To the customer:

- Contractor nonperformance (default),
- Substandard performance,
- Training Management continuity, and
- Sole source contracts.

To the Contractor:

- Inaccurate cost estimates,
- Initial development cost - capital investment,
- Capital recovery factors,
- Cost of spares, and
- Vendor support.

In providing additional assurance for success with a service program as described above, the customer may want to consider competitive prototyping of simulator systems as a means of reducing consumer risk.(4) Because of the contractor's risk, and the fact that he will be providing a service using his own resources, the cost to the customer will be more realistic since unqualified bidders are less likely to attempt to buy into such a contract. This approach appears to be only a step beyond the Air Force training program for the KC-10 aircraft in that title to all training devices will rest in the Government. However, dominion and control of all devices will be retained by the contractor. The major differences between the KC-10 approach and the projected one is the use of an existing trainer as opposed to building and designing the simulator to a specific application.

A program to develop a new in-flight refueling aircraft and associated support systems for the United States Air Force was driven by DoD direction to make maximum use of off-the-shelf equipment items.(5) This approach was designed to minimize research and development costs during the acquisition process. Any deviation from this direction required prior approval. The review process leading to equipment selection was lengthy, complicated and enforced by government procurement directives. The particulars of this process are really unimportant for the purposes of this paper. Simply stated from the resources available, the Douglas manufactured DC-10 aircraft was selected as the prime equipment item for the program. Similarities in flight characteristics between the KC-10 and the DC-10 aircraft allowed the use of existing DC-10 flight crew training equipment and programs to train initial KC-10 flight crews.

American Airlines had previously procured a DC-10 simulator, developed an air crew training program and was providing training to the airline industry at their Dallas/Fort Worth facility. Through Douglas Aircraft, an agreement was reached with American Airlines to provide the DC-10 training programs for Air Force flight crews on an interim basis until KC-10 training programs and equipment could be developed. Subsequently, American Airlines was awarded a contract to procure the necessary equipment, and establish, operate, and maintain a KC-10 training facility at Barksdale Air Force Base, LA.(6) The equipment, once procured, tested and installed, will be owned by the Air Force. When the training facility becomes fully operational, the contract with American Airlines will revert to a service contract with assorted options which can be exercised over a thirteen year period. The only performance criteria will be to provide trained KC-10 flight crews for the Air Force.

Research by Mr. Dembroski and Dr. Gansler, as reported in Nov/Dec 81 Proceedings of the Interservice/Industry Training Equipment Conference, indicates that the government can expect long term cost reductions in the service portion of a service-only contract. This savings should result from the application of a 90 percent learning curve applicable to simulators. Savings may be in the form of either lower cost or increased performance. Savings realized in support costs are in addition to the obvious savings related to system acquisition.

SUMMARY

There are many problems encountered in the development, fielding, and support of a modern flight simulator. Problem areas exist in personnel, training, spares, maintenance and technology. Attempts have been made to isolate, manage, and solve these problems individually and collectively. Logistics however, is an interactive discipline encompassing all aspects of support. Logistics must play an active role <u>throughout the entire life cycle</u> of a system to achieve maximum cost effectiveness.

As this paper has endeavored to emphasize, the environment may dictate contractor support as the most logical, cost-effective support concept. But, regardless of the support concept involved, all requirements must be clearly stated in the early stages of acquisition and faithfully transmitted through the acquisition documents.

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NBC TRAINING REQUIREMENTS FOR THE INTEGRATED BATTLEFIELD

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ABSTRACT

The United States has paid little attention to nuclear warfare, biological warfare, and chemical warfare in the last decade. Meanwhile, the Soviet Union initiated an expansion of its chemical warfare program which has continued to grow at a greater rate than any aspect of their military force. Soviet policy closely follows the words of Marshal Zhukov who said in 1956, "Future wars will not be won with nuclear weapons and massed air power alone...biological and chemical weapons will be used to augment conventional and atomic warfare." The Soviets and their surrogates have used lethal agents in Afghanistan, Laos and Kampuchea. It is clear the Soviets have the capability and willingness to fight in a biological and chemical environment. Soviet training programs integrate chemical weapons systems with conventional and nuclear operations. Since conducting training in one or any combination of these three special environments is not possible, United States preparedness to fight on a chemically, biologically, or nuclear contaminated battlefield requires the development of special training equipment, devices, and procedures which simulate these conditions as realistically as possible. To accomplish its mission, the US Army must train in peacetime as it will fight in war. This paper summarizes the needs of the US Army's requirements for training equipment and simulation to train in an NBC environment.

INTRODUCTION

Over the past several years, the world has witnessed the introduction of and growth in the use of chemical and toxic weapons against unprotected military and civilian populations in several wartorn countries. Despite denials by Soviet officials, overwhelming evidence is being accumulated to prove their complicity in and support of these murderous campaigns. In fact, the evidence has accumulated to the degree that the United States can no longer ignore the threat.

THREAT

Despite its long though sporadic history, chemical warfare did not become a modern world problem until World War I, when a total of 114,000 tons of chemical agents were employed producing 1,297,000 casualties. The Soviet Union alone suffered some 475,000 casualties, or 37% of the total. It has been suggested by some sources that it is these large losses which psychologically drive the Soviet leadership toward superiority in this form of warfare.

In 1975, Mr. Amos A. Jordon, then Assistant Secretary of Defense, stated to the House of Representatives that "The Chemical Weapons of the Soviet Union represent a serious potential threat." He went on to say, "We believe that the USSR is better prepared to operate offensively and defensively in a chemical environment than any other nation in the world." General David C. Jones, then Chairman of the Joint Chiefs of Staff, reiterated this position in 1981 when he concluded that "Warsaw Pact forces are better equipped, structured and trained than any other in the world for fighting in a chemical environment." There is a great deal of evidence to substantiate these observations.

There are many uncertainties inherent in any estimation of the current Soviet offensive capabilities. However, it is possible to get a feeling for the scope of these capabilities by examining some of the following data.

The Soviet Union has a large industrial base which could be mobilized to produce toxic chemical agents. Sources indicate that at one time some one hundred chemical plants were in operation, of which half were either producing or were capable of producing the latest agents. Best intelligence estimates indicate that the Soviets have between 350,000 and 700,000 tons of chemical agents ready for immediate use. It is further estimated that Tabun, a nerve agent, constitutes 50,000 tons of this stockpile. Although US intelligence believes that approximately one-third of the Soviet shells, rocket warheads, and bombs stored in Eastern Europe contain lethal chemicals, other sources indicate as much as a 50 percent fill. It appears that the Soviet stockpile is 7 to 10 times larger than that of the United States, and is sufficient to support 3 to 4 major offensives on a wide front. The Threat agents include the nerve agents, blood agents, blister agents, and toxins.

Although the Soviets had difficulty producing toxins, Tricothecenes are now in the Threat inventory. The LD 50s range from 0.1mg per kg to 1000mg per kg, depending on the particular toxin species and method of exposure. In addition to producing casualties, these toxins have the advantage of being an effective terror weapon. Disseminated as an innocuous powder, they cause blisters and vomiting, as well as severe bleeding. Since they are persistent, they also pose a long-term hazard.

The Soviets have artillery, mortar, and minefield delivery systems for chemical agents, as well as bombs and sprays for air delivery. Chemical rounds exist for the 122-, 130-, and 152-millimeter artillery. The BM 21 consists of a 40-tube multiple rocket launcher mounted on a URAL-375 truck. A battalion can deliver 720 rounds of the chemical-filled shells in a single ripple containing 3 tons of agent. The FROG and other surface-to-surface missiles allow the Soviets to extend the reach of their chemical weapons.

Superimposing the range of these weapons on a stylized US corps sector, shows that Soviet mortars and multiple rocket launchers can attack division targets from the FLOT well into the division rear. Targets include front-line troops and artillery units as well as some logistical targets. FROGs are capable of attacking targets up to the corps rear boundary, putting reserves and supporting units, as well as logistical complexes, at risk. SCUD and tactical air can reach transportation modes and major logistical support centers, well to the rear of the corps.

An estimated 80,000 to 100,000 Soviet chemical troops are available to provide support to combat troops operating in a chemically contaminated environment. In the ground forces, chemical units are organic down through regiments, and chemical personnel are assigned down through company-size units. Generally, a chemical defense brigade is assigned to a Soviet front, a battalion to each army and division, and a chemical company to each regiment. Chemical services provided include: rapid vehicle, clothing, terrain, and runway decontamination; warning of attacks, and chemical reconnaissance of contaminated areas.

To augment their capacity for fast, highly mobile warfare, and to protect themselves from CW agents, the Soviets have fielded the world's largest and most complete inventory of protective equipment. Their protective masks provide respiratory protection against all known chemical agents. Their combined arms protective suit can be worn as a coat, cape, or coverall. Although not airtight, the protective suit provides adequate protection against most chemical agents. To facilitate detection identification and delineation efforts, a variety of alarms and automatic contamination marking means are available. Decontamination assets include individual kits and truck-mounted equipment, including the TMS 65, a jet engine particularly effective in rapidly decontaminating large vehicles.

Soviet planners recognize that an effective chemical capability depends heavily on a comprehensive training program. Although precise figures are not available, it appears that 15 percent of the military training given to conscripts is devoted to NBC training, with extensive follow-on training being integrated throughout the remainder of their careers. Training is designed to physically and psychologically condition the troops to perform their combat assignments in full protective gear.

Many Soviet institutes and industries associated with chemical and medical research are also involved in chemical agent research and development (R&D). These programs are government controlled, and the open literature contains only carefully sanitized data. Some areas of interest appear to include efforts to synthesize additional G-type nerve agents, as well as extremely toxic organo-silitranes. The isolation, identification, and synthesis of toxins may well lead to a new era in chemical warfare.

It is clear that the Soviets can successfully conduct chemical warfare. The big question is whether they have the will to use these chemicals. In testimony before Congress in 1975, Lieutenant General Howard H. Cooksey answered this question when he stated, "The Soviets are so immersed in chemical weaponry, tactics, doctrine, equipment and personnel, and so much of their training centers around the use of lethal agents that it would be odd, from a military standpoint, if they did not employ them."

The threat is nothing new. At the end of World War I, General Pershing came to the conclusion that "Whether or not gas will be employed in the future is conjecture, but the eff . is so deadly to the unprepared that one can . afford to neglect the question." The United ates has neglected the threat over the last de e while the Soviets have been and are continuing prepare for large scale offensive and defensive N sarfare. They have the agents and delivery mea. and are continuing to invest in R&D efforts to en ance their capabilities. Their military forces are extensively equipped and well trained for operations in a contaminated environment. In a nutshell, there is a total Soviet commitment to NBC warfare.

THE CHALLENGE

The US Army recognizes this Soviet commitment and realizes that we must train to meet the threat. Since we do not conduct training in an actual NBC environment in peacetime (unlike the Soviets), US response to the NBC threat requires the development of a simulated-NBC environment to challenge our forces and allow them to train as they will have to fight. The US Army Chemical School has developed a Training Device Acquisition Strategy (TDAS) which summarizes the necessary concept to support training in a simulated-NBC environment. This document will serve as the principal instrument for directing the Army efforts to conceptualize, develop, and acquire training equipment, simulants, and support packages/procedures for this training. The TDAS supports the TRADOC goals of achieving substitution, simulation, and miniaturization where feasible/applicable. Thus far we have identified 22 proposed devices or systems for the TDAS.

SUMMARY

The systems and devices (see annex) discussed in this paper offer a challenge to all who are interested in establishing a realistic and viable NBC training environment. We've identified the threat, defined our requirements, and this convention has provided the forum to make our needs known to you, the innovators. Accept and meet this challenge and our fighting forces will immeasurably improve their capabilities in an NBC environment.

ANNEX

1. **Nuclear Weapons Effects Simulator**

a. Training/Simulation Requirement. Simulate flash, bang, neutron and gamma radiation, mushroom cloud, electromagnetic pulse (EMP), and transient radiation electronics effect (TREE); exercise troop reaction to nuclear burst; exercise NBC Warning and Reporting System (NBCWRS); exercise C^2 procedures.

b. For Use At: Armywide, National Training Center, US Army Chemical School.

c. Characteristics of Desired Device/Facility.

(1) Flash must be distinctive, observable under combat conditions, with a range of 5 to 15 kilometers.

(2) Bang must be distinct, distinguishable from battle sounds, with a range of 5 kilometers.

(3) Time between flash and bang must parallel that of a nuclear weapon for use in the NBC reporting system.

(4) Simulate real time and realistic generation of prompt neutron and gamma radiation.

(5) Produce a mushroom cloud with measurements and duration effect comparable to the measurements of 1-KT, 5-KT, and 20-KT weapons.

(6) Simulate electromagnetic pulse (EMP) and transient radiation electronics effect (TREE).

d. Status.

(1) Fielded: The M142 Nuclear Burst Simulator is inadequate. Troops do not recognize it as a nuclear burst, particularly in vehicles. It is not distinctive under combat conditions and does not simulate radiation effects. Exercise of NBCWRS is marginal.

(2) In development: Preliminary study by Science Application, Inc.

(3) Proposed device/system: Nuclear weapons effects simulator (NWES).

2. Total Dose/Dose-Rate Simulator

a. Training/Simulation Requirement: Simulate dose rates and total dose from induced/fallout radiation, as well as initial dose-rate readings.

b. For Use At: Armywide, National Training Center, US Army Chemical School.

c. Characteristics of Desired Device/Facility

(1) Simulate real time and realistic readings on radiacmeters and dosimeters.

(2) Total dose and dose rate must be measurable over time and location.

d. Status.

(1) Fielded: The AN/TDQ-11(V) trainer only interfaces with the IM-174 radiacmeter and simulates dose rate only. Total dose is not measurable.

(2) In development: None.

(3) Proposed device/system: Total dose/dose-rate simulator (TDDRS).

3. Radiation Automatic Casualty Assessment System

a. Training/Simulation Requirement: Assessment and assignment of initial and delayed radiation casualties.

b. For Use At: Armywide, National Training Center, US Army Chemical School.

c. Characteristics of Desired Device/Facility:

(1) The system should be near real time and provide total simulated casualties and radiation doses.

(2) The system should be realistic and indicate to personnel that they are casualties.

(3) For delayed casualties, the system must be realistic and provide total simulated incapacitation and total dose for each individual.

(4) The system should provide assessment of degradation on performance as a result of radiation exposure and a time tag for incipient casualties to be incapacitated at a later time.

d. Status:

(1) Fielded: None.

(2) In development: None.

(3) Proposed Device/System: Radiation Automatic Casualty Assessment System (RACAS).

4. Biological Agent Simulant

a. Training/Simulation Requirement. Simulate the effects of biological agents to include toxins used by Threat forces; reaction to biological agent; and equipment and personnel decontamination training.

b. For Use At: Armywide, National Training Center, US Army Chemical School.

c. Characteristics of Desired Device/Facility.

(1) The simulant agent or family of simulate agents must realistically simulate the physical properties of Threat agents.

(2) It must be suitable for equipment and personnel decontamination training, using standard procedures with a decontamination simulant.

(3) The simulant must contain a tracer capable of easy removal for use in evaluation of decontamination training procedures.

(4) The simulant must be capable of quenching itself and become nonactive 4 to 24 hours after application, so the training area may be used again without interference.

d. Status.

(1) Fielded: None.

(2) In development: None.

(3) Proposed device/system: Biological agent simulant (BAS).

5. Biological Agent Casualty Assessment System

a. Training/Simulation Requirement. Simulate the assessment of biological agent casualties.

b. For Use At: National Training Center.

c. Essential Characteristics.

(1) The system should work in conjunction with existing and future biological agent alarms.

(2) The system should work in conjunction with individual masks and collective protection systems.

(3) The system should assess and assign biological casualties.

(4) The system should indicate to personnel that they are casualties.

(5) The system should assign and assess incapacitated personnel.

d. Status.

(1) Fielded. None.

(2) In development: The simulated area weapons effects (SAWE) project currently being performed by Jet Propulsion Laboratory under contract to PM Trade to determine the best technical approach (BTA) to simulate the effects of area weapons during force-on-force training exercises.

(3) Proposed device/facility: Biological agent casualty assessment system(BACAS).

6. Biological Detection and Alarm Training Simulator

a. Training/Simulation Requirement. Activate biological detection and alarm systems in a training environment; properly employ biological alarm; react to biological attack.

b. For Use At: Armywide, National Training Center, US Army Chemical School.

c. Characteristics of Desired Device/Facility

(1) Must have a built-in training mode in addition to the operational mode.

(2) The training mode must not defeat the operational mode.

(3) The training mode must be built in or allowances must be made for it in all operational systems under development.

(4) Must be capable of being activated remotely.

d. Status:

(1) Fielded: None.

(2) In development: None.

(3) Proposed device/system: Biological detection and alarm training simulator (BDATS).

7. Biological Agent Decontamination Simulant

a. Training/Simulation Requirement. Decontaminate biological agent simulators.

b. For Use At: Armywide, National Training Center, US Army Chemical School.

c. Characteristics of Desired Device/Facility:

(1) The decontamination simulant must decontaminate the biological agent simulant.

(2) The simulant must be able to be used in all approved and developing decontamination systems and/or their associated training devices.

(3) The procedures used to decontaminate must duplicate the procedures used to decontaminate Threat agent.

d. Status:

(1) Fielded: None.

(2) In development: None.

(3) Proposed device/system: Biological agent decontamination simulant (BADS).

8. Chemical and Biological Agent Delivery System

a. Training/Simulation Requirement: Simulate delivery systems for Threat chemical and biological agents.

b. For Use At: Armywide, National Training Center, US Army Chemical School.

c. Characteristics of Desired Device/Facility:

(1) The system must provide the same cues the Threat system provides.

(2) The system must duplicate the dispersion patterns and area coverage of the Threat system.

(3) The system should be reusable and easily filled.

(4) The system should make use of a persistent chemical agent simulant and a biological agent simulant.

d. Status:

(1) Fielded:

(a) M9 SPAL has a limited ability to simulate artillery-delivered chemical agents. Area coverage is insufficient.

(b) Aero 14B aerial spray tank is in the inventory. It can be used to disseminate liquid chemical agents. It is not compatible with multiservice tactical aircraft.

(c) The M5 riot control agent dispenser is limited in its ability to deliver chemical agent simulants.

(2) In development: A training system for chemical defense (Phase II), using the XM267

launcher and XM11 SPAL simulates artillery-delivered chemical agents.

Restrictions on emplacement and use for safety reasons limit the effectiveness and realism of the system, making the training effects questionable.

(3) Proposed device/system: Chemical and biological agent delivery system (CBADS).

9. Nonpersistent Chemical Agent Simulant

a. Training/Simulation Requirement: Simulate nonpersistent chemical agent/agents used by Threat forces; react to chemical attack.

b. For Use At: Armywide, National Training Center, US Army Chemical School.

c. Characteristics of Desired Device/Facility:

(1) The simulant agent or family of simulant agents must realistically simulate the physical properties of Threat agents.

(2) The simulant must be capable of quenching itself and becoming nonactive 4 to 24 hours after application, so that the training area may be used again without interference.

d. Status:

(1) Fielded: N-butyl-mercaptan (BUSH) does not simulate the physical properties of Threat agent/agents. CS gives a misleading cue.

(2) In development: None.

(3) Proposed device/system: Nonpersistent chemical agent simulant (NCAS).

10. Persistent Chemical Agent Simulant

a. Training/Simulation Requirement: Simulate persistent chemical agent/agents used by Threat forces; react to chemical agent; suitable for equipment and personnel decontamination training.

b. For Use At: Armywide, National Training Center, US Army Chemical School.

c. Characteristics of Desired Device/Facility:

(1) The simulant agent or family of simulant agents must realistically simulate the physical properties of Threat agents.

(2) It must be suitable for equipment and personnel decontamination training using standard procedures with a decontamination simulant.

(3) The simulant must contain a tracer capable of easy removal for use in evaluation of decontamination training procedures.

(4) The simulant must be capable of quenching itself and becoming nonactive 4 to 24 hours after application so that the training area may be used again without interference.

(5) The simulant used to simulate mustard gas should contain in addition to the qualities listed previously, a time lapse development capability to simulate the delayed-casualty effects of mustard agents.

d. Status:

(1) Fielded: Polyethylene glycol (PEG) 200 does not simulate the physical properties of Threat agents. It is not suitable for evaluation of decontamination training procedures and is not capable of time lapse development.

(2) In development: Training system for chemical defense (Phase II) delivers PEG 200 using the XM267 launcher and the XM11 simulator projectile airburst liquid (SPAL). Restrictions on emplacement and use for safety reasons limit the effectiveness and realism of the system, making the training effects questionable.

(3) Proposed device/system: Persistent chemical agent simulant (PCAS).

11. IR Smoke Simulator

a. Training/Simulation Requirement: Provide a training device that will demonstrate the effects of infrared (IR)-defeating smoke.

b. For Use At: Armywide, National Training Center, US Army Chemical School.

c. Characteristics of Desired Device/Facility:

(1) IR sighting devices that simulate viewing into IR-defeating smoke.

(2) When used in conjunction with visual range smoke, it will simulate the full range of (IR-visual) smoke capability.

d. Status:

(1) Fielded: None.

(2) In development: None.

(3) Proposed device/system: IR smoke simulator (IRSS).

12. Chemical Agent Casualty Assessment System

a. Training/Simulation Requirement. Simulate the assessment of chemical agent casualties.

b. For Use At: National Training Center

c. Essential Characteristics.

(1) The system should work in conjunction with existing and future chemical agent alarms.

(2) The system should work in conjunction with individual masks and collective protection systems.

(3) The system should assess and assign chemical casualties.

(4) The system should indicate to personnel that they are casualties.

(5) The system should assign and assess incapacitated personnel.

d. Status.

(1) Fielded: None.

(2) In development: The simulated area weapons effects (SAWE) project currently being performed by Jet Propulsion Laboratory under contract to PM Trade to determine the best technical approach (BTA) to simulate the effects of area weapons during force-on-force training exercises.

(3) Proposed device/facility: Chemical agent casualty assessment system (CACAS).

13. Chemical Detection and Alarm Training Simulator

a. Training/Simulation Requirement. Activation of chemical detection and alarm systems in a training environment; proper employment of chemical alarm; and reaction to chemical attack.

b. For Use At: Armywide, National Training Center, US Army Chemical School.

c. Characteristics of Desired Device/Facility:

(1) Must have a built-in training mode in addition to the operational mode.

(2) The training mode must not defeat the operational mode.

(3) The training mode must be built in or allowances must be made for it in all operational systems under development.

(4) Must be capable of remote activation.

d. Status:

(1) Fielded: None.

(2) In development: The XM81 simulator is effective with certain limitations. The system with the training device on it does not replicate the actual system.

(3) Proposed device/system: Chemical detection and alarm training simulator (CDATS).

14. Chemical Agent Decontamination Simulant

a. Training/Simulation Requirement. Decontaminate persistent chemical agent simulants.

b. For Use At: Armywide, National Training Center, US Army Chemical School.

c. Characteristics of Desired Device/Facility:

(1) The decontamination simulant must decontaminate the chemical agent simulant.

(2) The simulant must be able to be used in all approved and developing decontamination systems and/or their associated training devices.

(3) The proposed simulation procedures must duplicate the actual procedures used to decontaminate the Threat agent.

d. Status:

(1) Fielded: None.

(2) In development: None.

(3) Proposed device/system: Chemical agent decontamination simulant (CADS).

15. Trainer Jet Exhaust Decontamination System

a. Training/Simulation Requirement. Simulate the operational and maintenance characteristics of the jet exhaust decontamination system (JEDS).

b. For Use At: US Army Chemical School.

c. Characteristics:

(1) The training device must provide the operator the opportunity to become proficient in the operation of the JEDS.

(2) The device must be able to duplicate the preoperational, operational, and postoperational checks and procedures.

(3) The device must be a reasonable facsimile of the decontamination operator's cab of the JEDS.

(4) When operating, the device must operate and sound like an actual JEDS. Additionally, the operator must be able to see a reasonable facsimile of the equipment being decontaminated.

(5) The training device must provide maintenance personnel the capability to troubleshoot and repair the JEDS.

d. Status:

(1) Fielded: None.

(2) In development: None.

(3) Proposed device/system: Trainer jet exhaust decontamination system (TJEDS).

16. Chemical Munition Training Devices

a. Training/Simulation Requirement. Develop training devices for US Army munitions.

b. For Use At: Armywide.

c. Characteristics of Desired Device/Facility:

(1) The training/simulation device must be identical in physical appearance to the actual system it is intended to simulate.

(2) The training device must be similar in operation to the actual system.

(3) The device must provide realistic training for artillery, EOD, and ammunition-handling personnel.

d. Status.

(1) Fielded: None.

(2) In development: None.

(3) Proposed device/system:

(a) Training binary chemical warhead: Multiple launcher rocket system (MLRS).

(b) Training projectile 155-mm GB-2.

(c) Training chemical warhead: Corps support weapon system (CSWS).

(d) Training projectile 155-mm binary intermediate volitility agents (IVA).

(e) Training projectile 8-inch VX-2 (IVA).

17. NBC War Games and Simulation Center

a. Training/Simulation Requirement. To provide students with realistic simulation (physical and mental sensations) of NBC effects and combat in an NBC environment.

b. For Use At: US Army Chemical School

c. Characteristics of Desired Device/Facility.

(1) Floor space measuring 33,000 square feet.

(a) Three large, 5,000-square-foot battle simulation rooms.

(b) Four smaller, 2,000-square-foot battle simulation rooms.

(c) Storage space measuring 10,000 square feet for props, mock-ups, chemicals, paper goods, electronic hardware, and computer and audio-visual software.

(d) Up-to-date military communication equipment.

(2) Access doors into larger studios and storage areas adequate for entry of large vehicles.

(3) In-house communication, closed-circuit TV (large screen), computers with display terminals and printers, and sound system.

(4) Maneuver and parking space for display/mock vehicles

(5) Soundproofing throughout building.

(6) Computer link with other stations.

(7) High output sound systems.

(8) Sensor-round battle theater.

(9) Recirculating, activated-charcoal-filtered air-conditioning system for at least one battle simulation room. Allows use of chemical simulants.

(10) Holographic hardware for 3-D simulation.

d. Status:

(1) Fielded. None. (Similar type facilities exist at Forts Benning, Rucker, and Knox.)

(2) Proposed Facility: A gaming/simulation facility supported by a core of in-house game players, instructors, and production and technical personnel. This section must be composed of individuals with a well-rounded knowledge of NBC doctrine, tactics, and methods of instruction. Eventually, this section will have to be able to export games/simulation to other NBC schools.

18. NBC Evaluation Training Facility

a. Training/Simulation Requirement: Exercise/evaluate NBC units in accomplishing NBC-related missions.

b. For Use At: US Army Chemical School.

c. Characteristics of Desired Device/Facility.

(1) An exercise/evaluation section to plan for and exercise/evaluate designated corps and divisional NBC units in NBC support-related missions.

(2) Equipment and personnel decontamination training to be conducted in the field.

(3) Live-agent decontamination training to be conducted at the chemical decontamination training facility.

(4) Nuclear reconnaissance to be conducted in a simulated nuclear-burst training area.

(5) A chemical reconnaissance training area to be established, using chemical simulants to detect/identify chemical agents.

d. Status.

(1) Operational: One decontamination training site exists for instruction at the US Army Chemical School. This is insufficient for unit needs.

(2) Under development: A live-agent training facility has been designed and budgeted for.

(3) Proposed facility/range: A nuclear and reconnaissance training area is proposed. This range is to be integrated with requirements associated with the present team facility and live-agent training facility.

19. Nuclear Accident/Incident Control Chemical Accident/Incident Control Training Site

a. Training Requirement: Provide a training area for nuclear and chemical accident/incident control training. (When the US Army Chemical School becomes the DOD Chemical School.)

b. For Use At: US Army Chemical School by students and area/DARCOM NAIC/CAIC teams.

c. Characteristics of Desired Device/Facility:

(1) Accident sites approximately 4 to 6 square kilometers each.

(2) NAIC site: Several different nuclear weapons training devices available to be placed on the site. "Seeding" with Alpha emitters to be considered.

(3) CAIC site: Accident scene reflects environmental release of toxic chemicals. Effects of chemicals to be simulated.

(4) Several scenarios developed to test the NAIC/CAIC team procedures for rendering safe, securing, cleaning up, and controlling an accident site.

d. Status:

(1) Fielded: Kirtland AFB, New Mexico, has a good NAIC site. Should the DOD Chemical School concept be approved, transfer of this mission from Kirtland AFB to Fort McClellan would be considered.

(2) Under development: None.

(3) Proposed Device/System: NAIC/CAIC training site.

20. NBC Computer-Assisted Training Module

a. Training/Simulation Requirement. To develop an NBC computer-assisted training (NBC CAT) module, similar in concept to the brigade/battalion level administrative or logistics module for battle simulation and war games or to First Battle. Purpose is to better train all individuals required to know NBC command and control techniques.

b. Characteristics of Desired Device/Facility.

(1) Flexible in design so that different levels of command--corps, divisions, brigade, battalion, and company--can practice NBC skills.

(2) Flexible in design so that different branches can relate to chemical module in terms of manpower and types of equipment.

c. Current Field System. Numerous war games are available now. Three are noted above, but there are others that could be used.

d. Concept of Development. NBC CAT module content and concept should be developed and coordinated so expert consultation and agreement is realized between the USACMLS game maker and branch users.

21. Multimedia NBC Threat Module

a. Training/Simulation/Support Requirement: Provide a classified NBC threat brief and an unclassified threat brief to Chemical School students, visiting VIPs, mobile training teams, and for exportable use.

b. For Use At: US Army Chemical School, area NBC schools, NBC sections, service schools.

c. Characteristics of Desired Device/Facility:

(1) Both the unclassified and classified briefing would consist of a 50-minute multimedia, audiovisual presentation that discusses the enemy's offensive and defensive capabilities and presents threat doctrine on the air-land battlefield.

(2) Both briefings should exploit the entire spectrum of audiovisual effects to produce a quality product (e.g., air-land 2000 briefing).

d. Status:

(1) Fielded:

(a) The US Army Chemical School has a relatively primitive classified and unclassified threat briefing.

(b) Intelligence and Threat Analysis Center, INSCOM, provides a classified briefing to COAC personnel.

(2) In development: None.

(3) Proposed Device/System:

(a) NBC threat briefing (classified).

(b) NBC threat briefing (unclassified).

22. Scale Model NBC Equipment

a. Training/Simulation Requirement: Compatible scale models of power-driven decontaminating apparatus and smoke generators are required to depict NBC units during terrain-board and sand-table exercises.

b. For Use At: US Army Chemical School, service schools, units (managed by TASC).

c. Characteristics of Desired Device/Facility.

(1) Models should be made of high-impact plastic and in compatible scales of available tactical vehicles.

(2) Moving parts are not required.

d. Status:

(1) Fielded: None.

(2) Under Development: None.

(3) Proposed Device/System: Scale model NBC equipment.

ABOUT THE AUTHOR

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CHARACTERISTICS OF FLIGHT SIMULATOR VISUAL SYSTEMS

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ABSTRACT

Some of the findings of AGARD FMP WG10 are discussed. Image detail and resolution are two characteristics of visual simulation systems which seem to be significant in determining pilot performance in a simulator. MTFA has been found to be a reliable metric for predicting target acquisition performance, however, present measurement techniques are not suitable for moving imagery. Reliable techniques for the measurement of both image detail and resolution need to be developed. Apparent motion as opposed to real motion is also discussed. Neither the effect of visual simulation characteristics on apparent motion nor the effect of apparent motion on pilot performance are well understood and require further research.

INTRODUCTION

Working group 10 was established by the Flight Mechanic's Panel (FMP) of the Advisory Group for Aerospace Research and Development (AGARD) in March 1979 to consider and report the characteristics of flight simulator visual systems. (1) The main task of this working group was to identify and define the physical parameters which characterise and determine the fidelity of visual systems, and to recommend techniques for measuring these parameters. This paper is based on the findings of the working group.

Considerable progress has been made in visual simulation technology, particularly in the area of computer image generation. It is still necessary, however, to make many compromises during the design of a visual system before finding a solution which is both technically sound and economically feasible. Ideally, the tradeoff decisions which must be made require answers to the following questions:

(a) What visual cues does a pilot use when flying aircraft in specific missions or tasks?

(b) How should the characteristics of the visual simulation system be specified to enable those cues to be presented to the pilot with sufficient fidelity to allow the given task to be performed?

(c) How well should a pilot be able to perform to obtain useful training, or to provide useful data to the research engineer or psychologist, or to enable his performance in an aircraft to be predicted?

Some of these questions have been addressed by the AGARD joint working group of the Aerospace Medical and Flight Mechanic's Panels on fidelity requirements of simulation for training purposes. (2)

It is apparent, however, that complete answers to these questions do not exist and that the designer must rely on a combination of data currently available, experience with previous simulations and intuition.

The FMP working group 10 was neither tasked with nor qualified for the address of the three questions, but restricted itself mainly to the question of which parameters should be measured and how they should be measured. If we are to be able to relate pilot performance to a set of physical parameters, we must have a relevant set of parameters and reliable methods of measurement.

The working group divided the physical parameters into three basic categories of spatial, energy and temporal properties corresponding to the fundamental quantities of length, mass and time. The following is a discussion of certain aspects of each category.

SPATIAL PROPERTIES

This section of the report covers metrics associated with field of view, depth, geometric distortions and scene content. The last of which is sufficiently intriguing to be discussed at length. The term scene content is used here to describe scene complexity or image detail density and is not related to the artistic nature of the scene. It is recognised that artistry can have a considerable impact on the usefulness of a scene but no attempt was made to define this parameter in the report.

The current nature of computer-generated systems does not allow highly detailed images. Users are constantly demanding more detail. There is evidence to suggest that an observer's ability to judge his position and velocity relative to his immediate environment depends not only upon the quality and geometry of the visual stimuli but also upon their quantity. Answers to the second question raised in the introduction therefore may require measurement of image content. These measures may assist users to specify their requirements.

Cohen et al[3] measured the spectrum of the luminance in natural scenes by analysing television video signals. They found that the luminance spectra of natural scenes could be approximated by a function that varied with the inverse square of the spatial frequency. They also found that the power spectrum of randomly spaced luminance steps having a random distribution of luminance values also exhibits the inverse frequency squared function. They speculated, therefore, that natural scenes can be thought of as an array of step luminance transitions having random spatial and magnitude distributions.

This led one member of the working group to speculate that scene content could be described by the density of the luminance or colour transitions within the scene.

The number of luminance or colour transitions in a given solid angle of a visual scene may be measured by an edge scanner that counts the number of observable edges in a given scan direction. Take several samples across the scene in orthogonal directions and obtain an average number of edge transitions in each direction. The square root of the product of these two numbers is a measure of scene complexity. The luminance/colour transition density is then obtained by dividing this number by the solid angle subtended by the scene. A number of photographs were analysed and values varying from 0.11/deg.^{2} for a colour photograph of a wooded canyon to 0.003/deg.^{2} for a CGI country scene were obtained.

A certain amount of research would be necessary to establish the value of such a metric and whether other measures might be more appropriate.

ENERGY PROPERTIES

Those properties associated with radiant power were deemed to belong in this section of the report. Luminance, contrast, colour and noise were fairly easy to define and established techniques exist for their measurement. Colour is somewhat interesting because little data exists to indicate its usefulness in a simulator either for training or research. Resolution, which should perhaps belong in the spatial section, is the most difficult to specify and is probably the most familiar characteristic of a visual system.

Our understanding of resolution is only slightly greater than that of scene content. The report defined the resolution of a visual system as its ability to present small recognisable details. In recognition of the fact that flight simulators invariably require moving imagery, the definition should probably be modified to include the ability to present small movements or changes in shape of image details. The ability of the human visual system to discriminate fine detail is termed visual acuity. The various types of visual acuity are defined as follows:

(a) Minimum separable acuity is the ability of the eye to separate two small objects.

(b) Minimum perceptible acuity is the eye's ability to detect a small object.

(c) Vernier acuity is the ability to align two objects such as two straight lines.

(d) Stereoscopic acuity is the ability to detect a difference in depth between two objects using both eyes.

(e) Motion acuity is the ability of the eye to detect the motion of small objects.

The significant aspects of each type of acuity are described in the report. They are all relevant to visual simulation system design although usually only the first of the five, minimum separable acuity, is specified in a procurement. Minimum separable acuity (often called visual acuity, or V.A.) has an important effect on all types of acuity but the relationship is seldom linear and other parameters may have even greater significance. Matsubayashi (4) found that reducing the acuity of one eye to 0.3 had little effect on stereoscopic acuity whereas further reduction had considerable effect. Researchers at the Boeing Aerospace Company have recently obtained similar results when the acuity of both eyes was reduced.

Minimum perceptible acuity is a function of the length of the object. A human hair is clearly visible on a CRT driven from a television camera even though its width is an order of magnitude less than the size of object which the system bandwidth might be expected to display. It is interesting to note that algorithms emulating such performance are being developed by CGI systems and the results are proving very effective.

Vernier acuity is an important factor in flight tasks such as hovering, formation flying and inflight refueling. Continuous sampling processes such as the horizontal scan of a normal television camera allow vernier acuity to approach that of the human visual system even though the minimum separable acuity may be quite low. Discrete sampling processes such as a raster structure severely limit vernier acuity although it is interesting to note that relatively high vernier acuity can be obtained across the raster of a CRT providing the raster structure is visually suppressed. Temporal characteristics such as threshold and hysteresis will also affect both vernier acuity and motion acuity.

All the above-mentioned types of acuity are greatest, i.e., have lower angular thresholds in the foveal region of the eye. Figures 1 and 2 show how V.A. and motion acuity vary with retinal eccentricity. The effect of luminance and contrast on visual acuity are discussed at length in the working group report but the general effect on V.A. is shown in Figures 3 and 4.

Measurement of Resolution (Minimum Separable).

The concept of limiting resolution has been used by the television industry for many years. It is, however, an unreliable measure. Differences of up to 25% can be obtained by merely changing the length and number of lines in the displayed bar patterns and even casual observers can detect considerable differences in

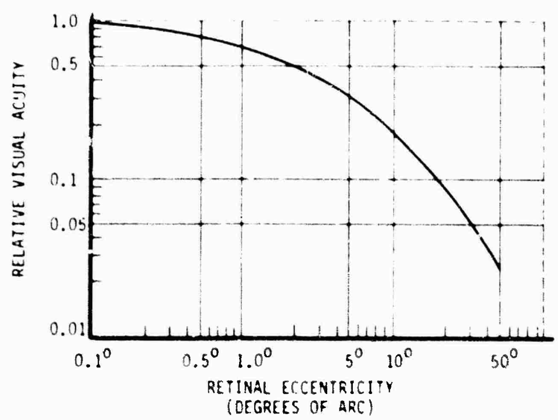

FIGURE 1 VARIATION IN VISUAL ACUITY WITH RETINAL ECCENTRICITY (FROM W.S. SMITH)

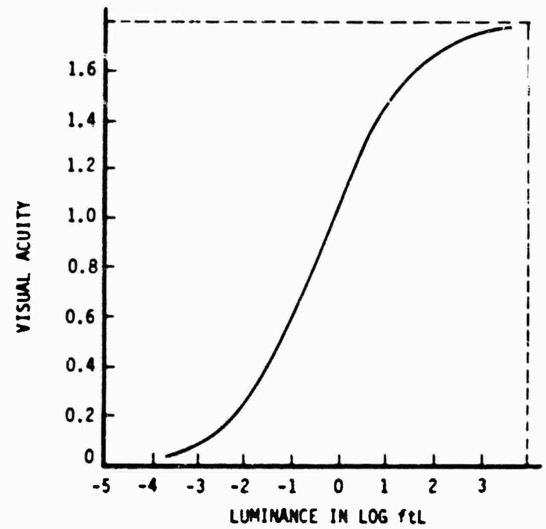

FIGURE 3 VARIATION OF V.A. WITH LUMINANCE (CONE VISION ONLY). (FROM KONIG)

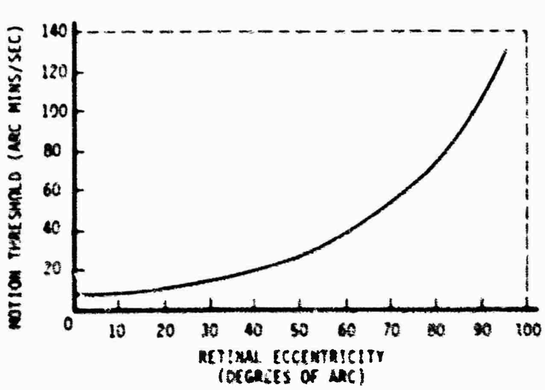

FIGURE 2 MOTION THRESHOLD FOR CIRCULAR TARGET SUBTENDING 0.5 DEGREE. BACKGROUND LUMINANCE ~ 14 ftL; TARGET LUMINANCE ~ 7 ftL. (FROM SALVATORE 1978)

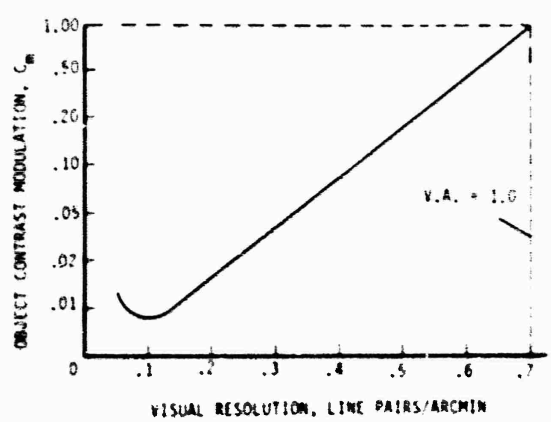

FIGURE 4 OBJECT CONTRAST MODULATION, $2B/2B_{av}$, NECESSARY FOR EYE TO RESOLVE A PATTERN OF ALTERNATING DARK AND BRIGHT BARS OF EQUAL WIDTH (B_{av} = 35 cd/m²)

picture quality between systems having the same limiting resolution. The most widely accepted method for measuring resolution is the generation of a Modulation Transfer Function (MTF) using a sinusoidally modulated test pattern. The input test pattern is 100% modulated and the output modulation is plotted against spatial frequency which produces a plot similar to that shown in Figure 5. Such a curve gives a fairly adequate description of the resolution characteristics of most displays and can be used to predict operator performance for a number of visual tasks.

Care should be taken when specifying or interpreting MTF's. Optical systems generally have a different MTF for radial and tangential lines and any sampling techniques such as a raster structure or the shadow mask of a colour CRT will have a considerable effect on spatial frequencies greater than half the sampling frequency.

Although the MTF curve is a useful measurement for a visual system, it does not give a unique figure of merit enabling comparisons to be made between visual systems. Charman and Olin(5) proposed the use of the area between the MTF curve and the threshold detectability curve as a measure of image quality for photographic systems. The metric was called the threshold quality factor and has been applied to electrooptical systems in general under the name of modulation transfer function area (MTFA). The threshold detectability curve would normally be that of a human observer but may be modified by other system characteristics. Figure 6 shows typical MTF curves for an optical display system together with a threshold detectability curve for a typical observer. The areas between the threshold detectability curve and the MTF curves represent the radial and tangential MTFA for this particular system under the conditions of the measurement. Snyder (6) has shown that MTFA can be used to predict probability of recognition of real-world targets displayed on a CRT. Varying amounts of video noise were added to elevate the detectability threshold curve.

An interesting experiment was performed by Boynton and Boss (7) to determine the effect of contrast and illumination on target recognition. They presented arrays of small dark circles to a number of observers. Half the arrays had a square substituted for one of the circles and the task was to say whether a square was present or not. The illumination of the arrays and the contrast of the targets were varied and the percentage of targets reported was plotted against time (see Figures 7 and 8).

The design of the apparatus was such that high contrast could be maintained at spatial frequencies somewhat beyond those useable by the eye and the control of contrast was uniformly applied to all spatial frequencies.

The system resolution and observer threshold curves relevant to the case of 100% contrast targets and variable luminance can be depicted as in Figure 9. The resulting MTFA values can then be plotted against target recognition performance as in Figure 10.

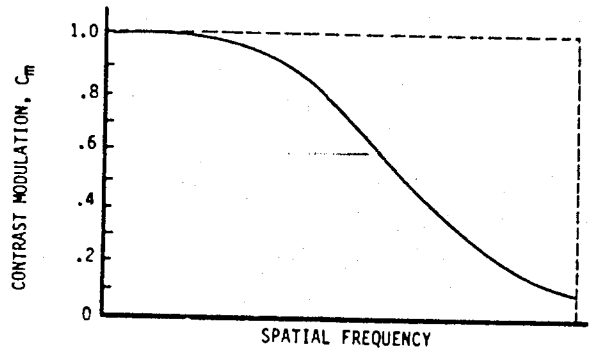

FIGURE 5 TYPICAL MTF CURVE

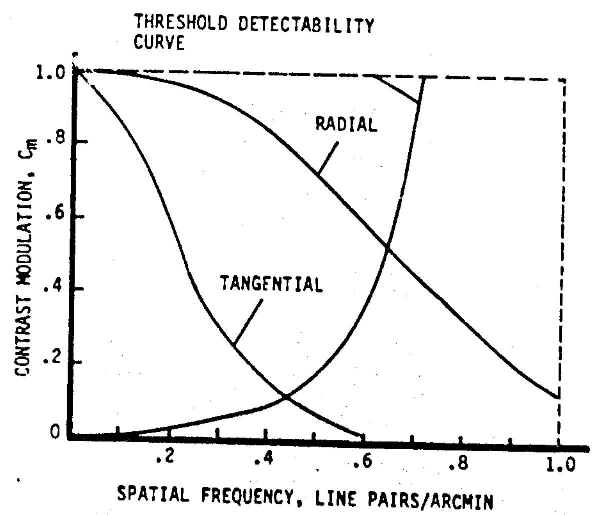

FIGURE 6 CONTRAST MODULATION CURVE FOR A WIDE-FIELD PUPIL-FORMING DISPLAY.

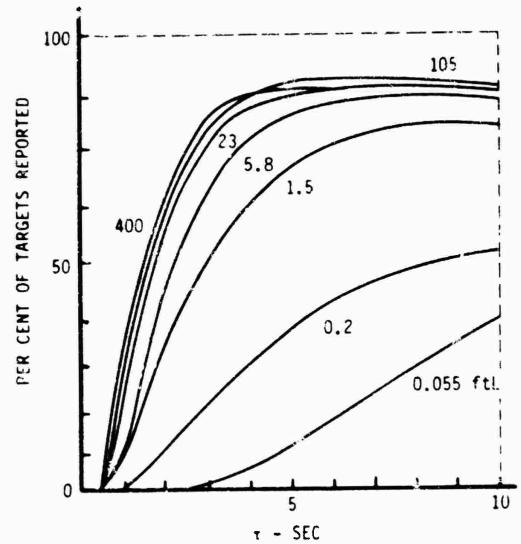

FIGURE 7 AVERAGE TARGET ACQUISITION CURVES FOR 100% CONTRAST TARGETS AT DIFFERENT BACKGROUND LUMINANCE LEVELS. (FROM BOYNTON & BOSS)

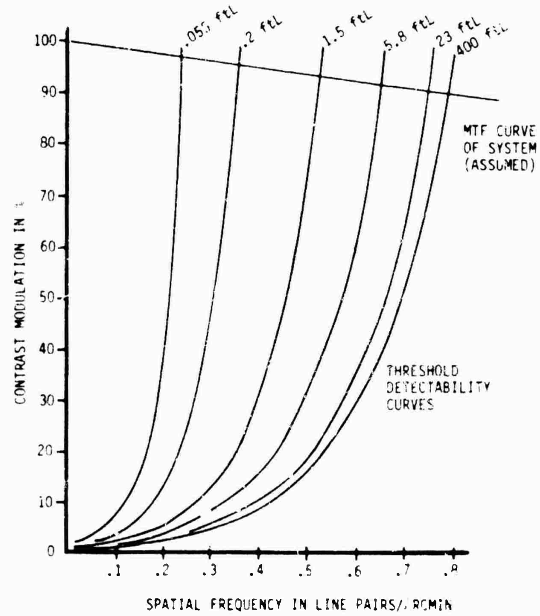

FIGURE 9 MTF OF APPARATUS AT 100% CONTRAST. THRESHOLD DETECTABILITY CURVES INTERPOLATED FROM FIGURES 3 & 4

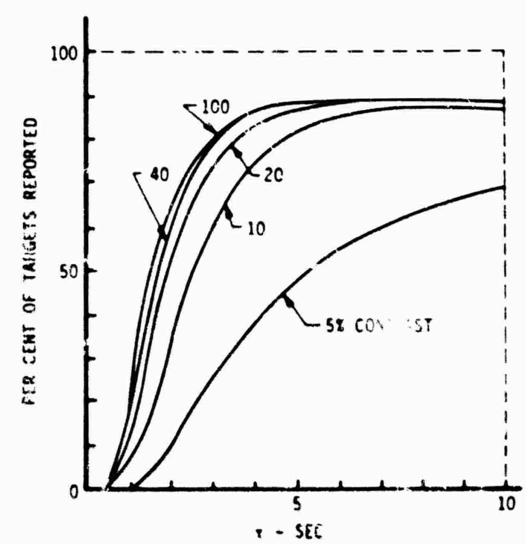

FIGURE 8 AVERAGE TARGET ACQUISITION CURVES FOR 400 ftL AT DIFFERENT CONTRAST LEVELS. (FROM BOYNTON & BOSS)

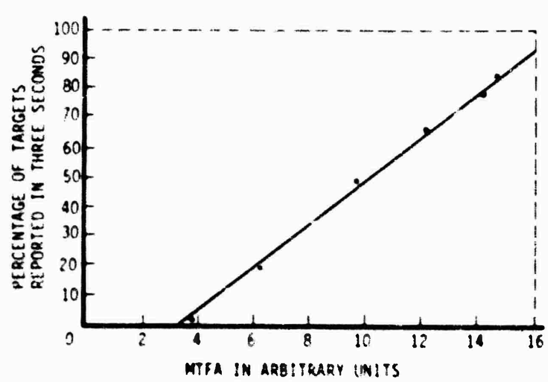

FIGURE 10 RELATION BETWEEN MTFA AND TARGET RECOGNITION USING LUMINANCE AS A VARIABLE.

The percentage of targets reported in three seconds has been used as a measure of observer performance. A three-second search task not only seems relevant to many flight tasks but was also used by Boynton in his own analysis of the data. Figure 10 shows a surprising degree of correlation between MTFA and observer performance under varying illumination levels.

In general, it would appear that MTFA can be used to predict observer performance in target acquisition tasks providing that the system MTF exhibits normal behaviour.

Dynamic Aspects of Resolution.

MTF curves and threshold detectability curves are normally obtained using static images. Unfortunately, the image presented to a pilot on a visual simulation system is seldom static. A much more relevant metric would be one that measures dynamic resolution. System MTF can be degraded considerably by such factors as TV camera lag, display decay time and various aliasing effects.

Threshold detectability curves will also be degraded at high image velocities by factors such as the image refresh rate and the basic parameters of the human visual system. It should also be realized that applying movement to the external environment as depicted on a visual simulation system, rather than to the aircraft itself as in the real world, may effect the performance of the human visual system.

Several techniques can be used for the measurement of static MTFA but no known techniques exist for the measurement of dynamic MTFA. A performance metric based on tasks similar to that used by Boynton and Boss seems to be an attractive method for measuring dynamic resolution.

TEMPORAL PROPERTIES

Establishing general procedures for the measurement of temporal properties is difficult due to the variety of techniques used for the generation of visual scenes. The following characteristics were determined to be significant and techniques for their measurement are described in the report of the working group.

- Excursion limits (i.e., maximum velocity)
- Time lags
- Noise
- Linearity
- Hysteresis
- Thresholds

These characteristics are applicable to all types of visual simulation and are particularly important when considering pilot or aircraft performance in closed-loop situations. Ideally, the measurements should be made at the pilot eyepoint.

Measurements made at the input to the display device are usually more convenient although allowances should be made for the properties of the display device or video link itself. Most of the characteristics will be affected in some way or other by the display, i.e., threshold will be affected by the vernier resolution and time lags will be affected by the refresh rate and response time of the displays.

Perhaps the most interesting aspect of the video link, and one about which we have very little knowledge, is the illusion of smooth movement created by television displays.

The phenomenon of apparent motion created by a succession of static images having appropriate spatial and temporal relationships has been known for many years. Apart from its obvious use in the television and motion picture industries, it has provided an interesting analytical tool which has generated a considerable amount of data concerning the conditions which enable smooth continuous motion, jerky motion or succession to be perceived. Many of the anomalies often seen in current visual simulation systems can be attributed to a change in the perception of apparent motion by the human visual system. Stroboscopic effects sometimes seen with runway markings are a good example of this. Interlace crawl (in which one-half of the raster lines seem to disappear while the remaining one-half move slowly up the screen) is caused by the interlaced raster structure being perceived as a set of horizontal lines moving a single line spacing in one field time. The breakdown of smooth motion seen on systems using random texture may be explained by Julesz's (7) experiments with random dot arrays. He found that the spatial separation between successive exposures could not exceed 15 arc minutes for motion to be seen. Smooth motion can be seen with discrete objects when the spatial separation is as much as 4°. Braddick (7) speculated that the difference was due to two distinct levels of processing in the visual system being responsible for the interpretation of apparent motion.

The motion is random dot arrays seems to be determined by a lower-level process based on directionally selective neurons while the more general form of apparent motion is determined by an upper-level process using interpretive techniques based on the overall situation.

The question arises as to whether or not our perceptual experience of apparent motion is different from that of real motion and whether or not the visual system characteristics associated with real motion can be applied to apparent motion. A corollary to this question would be to determine how the characteristics of apparent motion are affected by the characteristics of the display.

CONCLUSIONS

The main task of FMP Working Group 10 was to define the essential characteristics of visual simulation systems and to recommend suitable measuring techniques. A certain amount of research is still needed before a standard set of procedures can be recommended for all characteristics, however, such research will have limited value unless an attempt is made to answer the three questions raised in the introduction. These questions can perhaps be summarised by one, i.e., what visual cueing is necessary in a simulator to obtain effective training (or research)? One of the recommendations of the joint AGARD working group on fidelity requirements for pilot training was to establish AGARD working groups to pursue the entire training effectiveness question. AGARD cannot perform any research itself but the multinational, multidisciplinary approach used by AGARD seems ideally suited for the task of defining the required research.

Major General Abrahamson opened the 1980 Interservice/Industry Training Conference by giving the entire industry, including the users, a C rating as regards performance. An A rating is probably unattainable as it would imply perfection, however, it should be possible to achieve a B rating during this decade if a concentrated attempt is made to answer the training effectiveness question.

1 AGARD Advisory Report No. 164, Characteristics of Flight Simulator Visual Systems (1981)

2 AGARD Advisory Report No. 159, Fidelity of Simulation for Pilot Training (1980)

3 Cohen, R.W.; Gorog, I.; Carlson, C.R.; "Image Descriptors for Displays" Office of Naval Research Technical Report AD A00 7585, Arlington, VA, 1975

4 Matsubayashi, A.; "Forschung uber die Tiefenwahrnehmung", IX Acta Soc. Opthal. Jap 1938, German Abstract, IBID, 133; and Ber. G Es.Physiol., Vol. 112, pp. 290-291.

5 Charman, W.N.; Olin, A.; "Image Quality Criteria for Aerial Camera Systems", Photographic Science and Engineering, Vol. 9, No. 6, 1965, pp. 385-397.

6 Snyder, H.L.; Chap. 3 of "Perception of Displayed Information", edited by L. Biberman, Plenum Press, New York, 1973.

7 Boynton, R.M.; Boss, D.E.; "The Effect of Background Luminance and Contrast upon Visual Search Performance", Illuminating Engineering, April 1971, pp. 173-186.

8 Julesz, B.; "Foundation of Cyclopean Perception", Chicago; University of Chicago Press, 1971.

9 Braddick, O.; "A Short Range Process in Apparent Motion", Vision Research, 1974, 14, pp. 519-527.

ABOUT THE AUTHOR

Brian Welch obtained a BSc in Physics from University College, London, in 1960. He joined CAE Electronics in 1965 and has worked on several aspects of flight simulators. Since 1970 he has specialized in Visual Simulation and was responsible for the development of a modelboard visual system. He has been actively engaged in developing and promoting the use of head- and eye-slaved imagery for several years and is currently responsible for the development of a Helmet-Mounted Display for the U.S. Air Force which is being funded jointly by the U.S. and Canadian Governments.

FILTERING SIMULATED VISUAL SCENES — SPATIAL AND TEMPORAL EFFECTS

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ABSTRACT

In computer image generation (CIG) "spatial filtering" refers to the combining of tonal information from scene features inside and in the vicinity of a pixel to form the video for that pixel. Several investigators have recently proposed improved filters, validating their choices with pictures of sensitive test scenes. It can readily be shown that filters which produce the best static scenes generate serious artifacts when applied to dynamic field-rate update CIG. The investigations in the literature have not explored this topic. When some necessary conditions imposed by the temporal effects of interlace-scan systems are applied to the algorithms, the differences between simple filters and the more complex filters become quite minor, even on the static test scenes. On CIG training scenes, designed to simulate the real world, the differences in results of a variety of filters become imperceptible.

SPATIAL FILTERING

When computer image generation is used for visual scene simulation, the scene is computed as a large number of discrete values of video. Each computed value applies to a defined distance along a scan line. This region, typically a square or nearly square area on the view window, is referred to as a "pixel."

Video for a pixel is formed using contributions from defined scene features -- faces, point lights, fog, texture, etc. Video may be formed from only one point in a pixel, using all information inside the pixel, or using scene information from a larger area containing the pixel -- all have been used. The contribution to pixel video of scene features may be uniform, Gaussian, bilinear, sine(π x)/x, or any other weighting..many have been used.

The process of forming pixel video according to a prescribed set of rules is generally referred to as spatial filtering. It has also been called anti-aliasing, anti-rastering, quantization smoothing, and other terms. Just as standard filtering can be shown to be equivalent to time convolution, spatial filtering is equivalent to space-domain convolution. Reference 1 examines this topic in some detail and concludes that performing the computations as convolution in the space domain leads to more efficient implementation than computing in the spatial frequency domain via transformation techniques.

A number of recently reported studies (2) (3) (4) (5) (6) make a case for a preferred spatial filtering technique. They are illustrated with scenes of very sensitive test patterns which do indeed show the superiority of the technique being discussed. This leaves unanswered two important questions. Have the temporal effects associated with interlace raster scan displays been adequately considered? Are the differences sufficiently great to be of significance for the scenes used in training systems?

Integration Filtering

Figure 1 shows a group of nine pixels, identified by their scan line number, I, and pixel number along a scan line, J. Video is to be determined for the center pixel. To the knowledge of the author no investigator has proposed that feature fragments outside a two by two pixel region surrounding the center make any contribution to the center pixel video.* Hence, only the portions of faces A and B shown inside the dashed lines will be considered. A weighting function, W(I,J) defines the desired filter --the origin is translated to the center of the pixel being computed. For each face, the color is defined by the red, blue, and green components. Further, due to a variety of types of modulation, these will themselves be functions of I and J; $R_A(I,J)$, $B_A(I,J)$, $G_A(I,J)$, $R_B(I,J)$, $B_B(I,J)$, and $G_B(I,J)$. Pixel video is computed by integrating over the area covered by face A the product of W and each of the face A color components, doing the same for face B (and others if there are more than two), and adding the results.

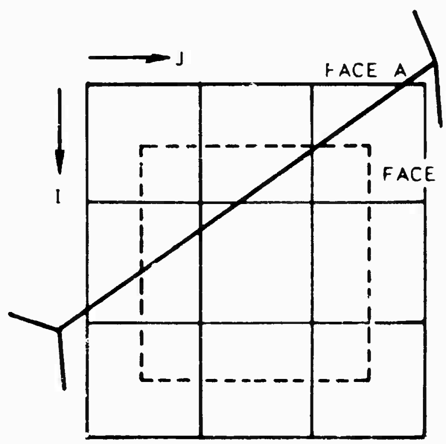

Figure 1. Integration Filtering

*Computation of combined optical and electronic transfer function for simulated displays of electro-optical viewing systems (forward looking infrared and low light level television) involves an exception to this statement. Weighted contributions of computed video from arrays as large as 9 x 9 pixels are used to determine the displayed video for the pixel in the center.

Oversampling Filtering

In oversampling each pixel is considered as an array of n by n subpixels, as illustrated in Figure 2 for n = 4. The weighting function is integrated over the area of each subpixel and the results are stored in a weighting table (referred to as an image plane convolution table in reference 1, and as a pre-computed lookup table in reference 2). These weights are multiplied by the face color components at the centers of the subpixels, and the results are summed to obtain the pixel video.

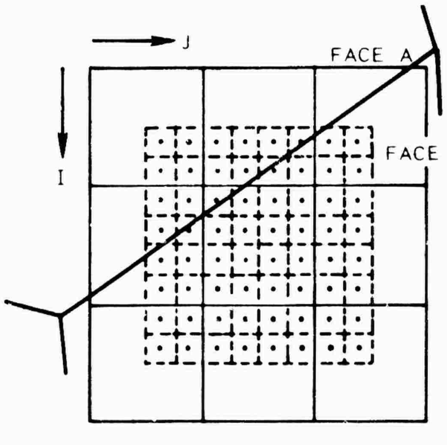

Figure 2. Oversampling Filtering

This process is sometimes discussed in terms implying it is an entirely different entity than integration smoothing as discussed above. It seems more enlightening to discuss it as a technique for approximating the exact results of integration smoothing. Thinking along these lines led to the following statement from Reference 3: "Since no improvement in image quality was perceivable for n greater than 8, we used this value as representative of exact area weighting." That is fully in agreement with our experience, applying to scenes using oversampling made in our laboratory since 1974. In fact, an n of 4 gives results whose differences from exact computation is barely discernible on sensitive test patterns. Considering the sizable reduction in computation required by the lower value of n, it seems a reasonable choice for real time hardware. A comparison of results in Figures 1 and 2 is instructive. If we assume uniform weighting, then integration smoothing gives 0.2158A + 0.7842B for the pixel, while oversampling smoothing gives 0.2188A + 0.7813B.

A Necessary Condition

In preliminary discussion to clarify some of the concepts, only one dimension will be considered. It will be assumed there is no variation along scan lines, but only vertical variation. Figure 3 identifies three scan lines, their sublines, and weights of subline contributions in formation of video for scan line # 87. First consider a uniform two-line weighting: a = b = c = d. If the entire view window is covered with a single face of intensity "1", the value of video for line 87 must be 1. The value computed from the designated weights is 2a + 2b + 2c + 2d. This sum must be 1, so each weight must be 1/8.

Now assume a horizontal stripe of intensity "1", just covering subline 2 of line 87. It makes a contribution of 1/8 to line 87 and a contribution of 1/8 to line 86, or a total contribution of 1/4 to the view window. If we shift this narrow strip vertically so that it covers any other subline, we find the contribution to the window remains unchanged. This pattern of weights thus meets a necessary condition stated by A.C. Erdahl, as quoted in Reference 4:

> The total energy contributed to all display pixels by a scene fragment should remain constant and be independent of its position relative to the pixel structure.

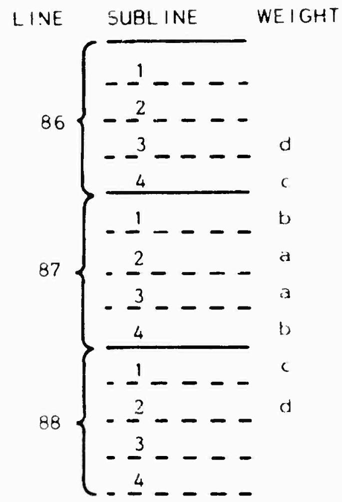

Figure 3. Subline weighting

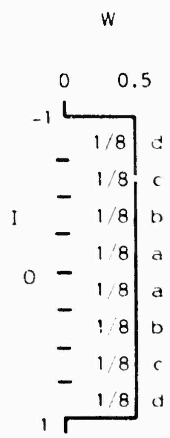

Figure 4. Uniform Weighting

In order for a set of weights, a,b,c,d to meet Erdahl's condition it is necessary that a + d = b + c = 0.25. To illustrate that this condition is far from universally recognized, one investigator produced scenes for evaluation using "Nonuniform weighting over a region covering only one sampling period." Since only one sampling period was covered, d = c = 0. Since nonuniform weighting was specified, a ≠ b. Hence the necessary condition could not be met, and it could be expected without the need for evaluation that the results would be unsatisfactory.

Reference 5 proposes triangular weighting of display spot intensity as optimum, in an investigation of display of sampled information. This represents a reasonable candidate for spatial filter investigation. Figure 5 shows the weights -- they meet the Erdahl requirement.

Reference 3 works from the ideal frequency domain filter and arrives at $W(I,J) = \sin(\pi I)\sin(\pi J)/IJ$ as the optimum weighting. Figure 6 shows this in one dimension, scaled so the total area is 1. Here a + d = 0.2385, b + c = 0.2645. This filter does not meet the brightness invariance requirement. Nevertheless, as shown by the scenes reproduced in the paper, it gives excellent results. This indicates that some departure from the equality ideal is tolerable. One might consider a little "fudging" of the weights of Figure 6 to make a+d=b+c. One has a strong suspicion such a process would end up giving the weights of Figure 5.

One other weighting pattern will figure in subsequent discussion, and hence will be defined here. It is the single-line uniform weighting illustrated in Figure 7. Applied in two dimensions, this gives uniform weighting over a single pixel. This has been the weighting function most widely applied to real time systems to date.

TEMPORAL EFFECTS

Raster-scan display devices paint first the odd-numbered scan lines, then the even-numbered scan lines -- the odd field plus the even field comprise a frame. With U.S. television standards, each field is 1/60 second; a frame is 1/30 second.

Early CIG systems employed frame-rate update. Thirty times a second updated viewer position and attitude data and moving target location and attitude data, were applied to generation of video for the next frame. This led to a number of undesirable effects; a step effect and a "comb" effect associated with high contrast moving edges, doubling of lights and other small

Reference 4 addressed some of the topics discussed above, but did not explore the full impact on the selection of filter algorithms.

To extend Erdahl's statement to deal with interlace effects, it must apply not to the frame, but to each field generated. Let's investigate quantitatively what this implies.

Figure 8 shows a face covering scan line 87 at the time the odd field is being calculated. Lines 86 and 88 get zero contribution, since they are in the even field. Lines 85 and 89 get zero since they are outside the range influenced by the face in the location shown. Line 87 gets a contribution of 2a + 2b. Figure 9 shows the same configuration with the weights applicable during the generation of the even field. The total contribution of the face to the scene is 2c + 2d.

Figures 10 and 11 show contributions when the face is bisected by a scan line boundary. In both cases the total contribution is a+b+c+d. The requirements established earlier: a+d=b+c=0.25 still apply since even with field rate update the scene may be stationary.

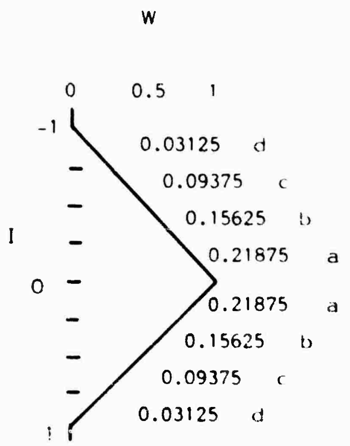

Figure 5. Triangular Weighting

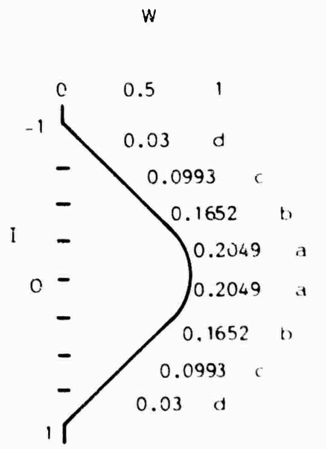

Figure 6. Sin (πI)/I Weighting

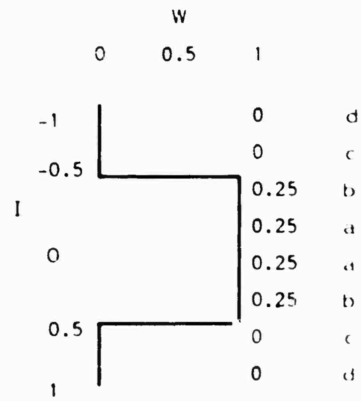

Figure 7. Single Line Uniform Weighting

features at certain rates of movement, and in general a lack of smoothness in perceived motion. Updating the scene at field rate requires only modest increases in hardware, it solves or greatly improves the effects listed above, but it introduces a new undesirable effect.

Assume the filter of Figure 7 is being used. Assume a horizontal face one scan line high on the view window. Assume further that this face is moving vertically at the rate of one scan line per field time. If the face is located on an even scan line when the odd field is being computed, and on an odd scan line when the even field is being computed, it will contribute zero brightness to the scene. If the converse is true, if it is located on a scan line of the field being generated, it will contribute its full intensity twice per frame. Both effects are incorrect. If the face is moving at a slightly different rate, it will appear and dissappear. If it is inclined slightly from the horizontal and moving, face breakup will appear.

Summarizing requirements, we now have: 2a + 2b = 0.5, 2c + 2d = 0.5, a + b + c + d = 0.5, a + d = 0.25, b + c = 0.25. The uniform weighting of Figure 4 obviously meets all these requirements, but the requirements as stated do not absolutely dictate this distribution. Consider a = 0.15, b = 0.1, c = 0.15, d = 0.1. These satisfy the above equations. However, a look at Figure 12 showing the shape of the distribution giving this set of weights indicates it to be absurd. When an interlace display system is used with a CIG system with field rate update, it is necessary to apply the uniform distribution of Figure 4 in the scan-line direction. We applied it on a real-time system in our laboratory in 1977, and it not only solved the twinkling face and light problem, but unexpectedly produced significant improvement in the interlace-caused step effect.

The above establishes required filter shape in the vertical direction, but still leaves us with a degree of freedom in the horizontal direction.

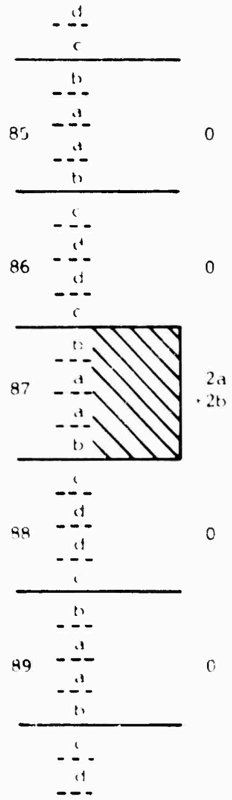

Figure 8. Face on Scan Line. Contribution to Odd Field

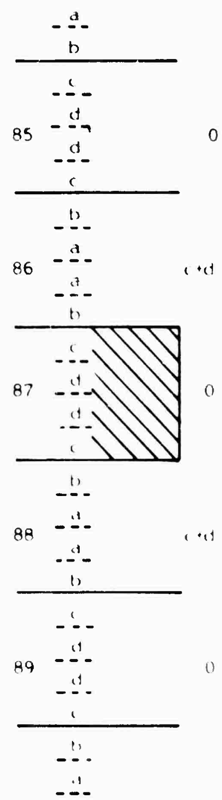

Figure 9. Face on Scan Line. Contribution to Even Field

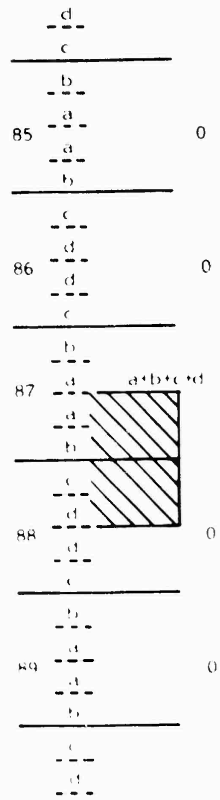

Figure 10. Face Bisected by Scan Line Boundary. Contribution to Odd Field

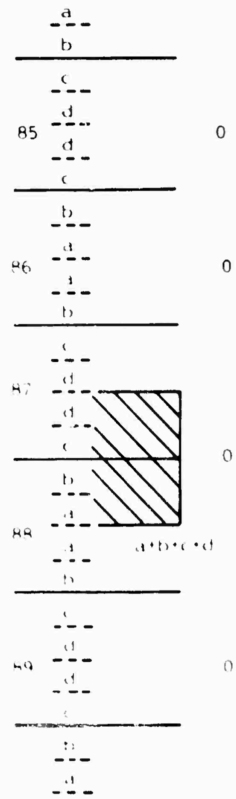

Figure 11. Face Bisected by Scan Line Boundary. Contribution to Even Field

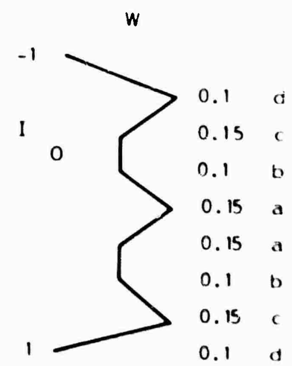

Figure 12. Weighting Which Meets Necessary Conditions Established So Far; Yet is not Satisfactory.

TWO-DIMENSIONAL WEIGHTING PATTERNS

Figure 13 shows an isometric representation of a two dimensional weighting pattern in which the weight is displayed as height. It is the one proposed in Reference 3

$$W = 0.067728 \frac{\sin(\pi I)\,\sin(\pi J)}{I\,J} \qquad |I| \le 1,\ |J| \le 1$$

in which the scale factor is chosen to make the total integrated weight (the total volume under the surface shown) equal to one

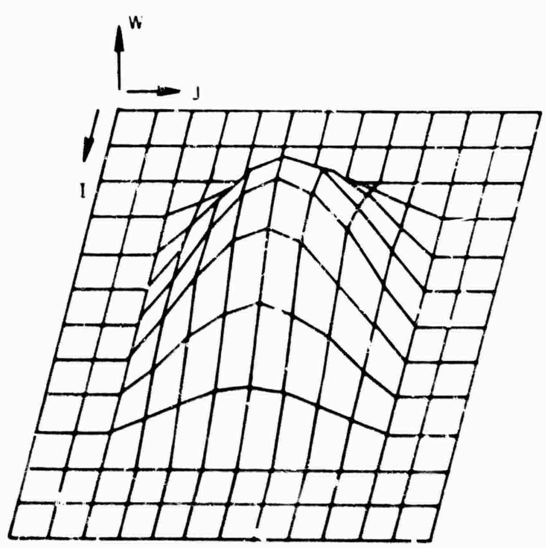

Figure 13. Isometric Depiction of Two-Dimensional Weighting Pattern

Figure 14 shows an alternate depiction of the same information, with separate portions of the figure showing the portion of the view window within which scene features affect video for the center pixel, the weight as a function of J for I = 0, and the weight as a function of I for J = 0. The weighting functions for the filters investigated in this study will be shown in this manner.

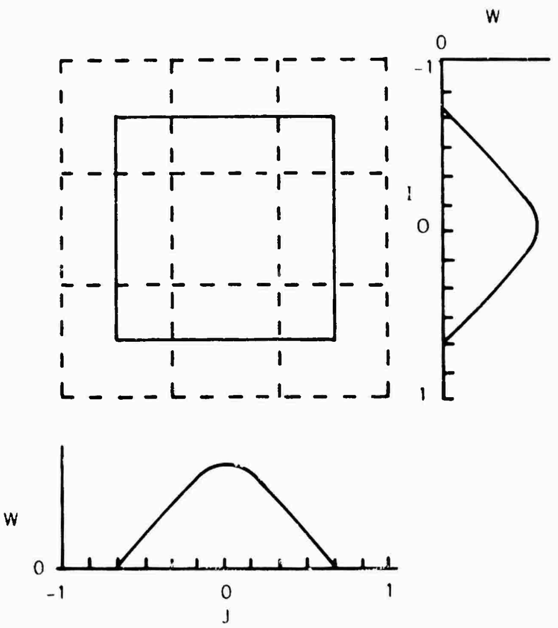

Figure 14. Alternate Depiction of Two-Dimensional Weighting Pattern

Brightness Consistency in Two Dimensions

Figure 15 shows a group of pixels surrounding pixel 103 of scan line 87. The subpixels whose scene content contributes to the video of the center pixel are shown, with labels designating the weight of their contributions. Any weighting scheme will be symmetrical about the vertical and horizontal axes; hence, if we consider the weights in the upper left quadrant the same results will apply to the remaining quadrants.

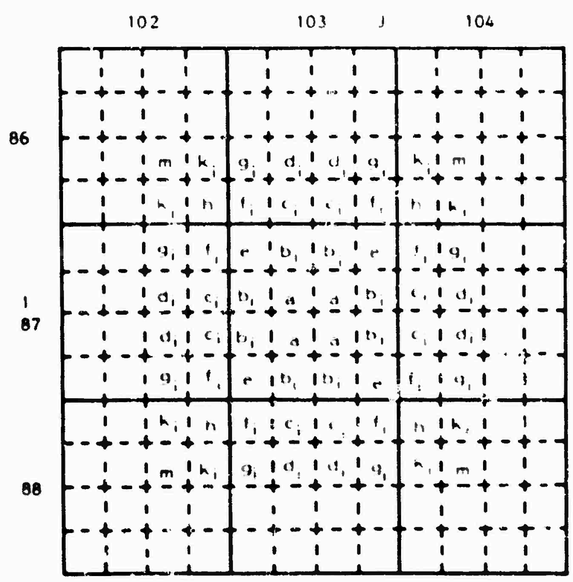

Figure 15. Subpixel Weight Identification

Consider the subpixel labelled "e" in the upper left quadrant. A face exactly filling this subpixel will contribute to the brightness of pixel 102 of line 86. If we mentally move the weighting table to be centered on this pixel, we find subject subpixel contributes a weight of "h" to pixel 102 of line 86. Continuing the analysis, we get the following results:

	Contribution To				Total
Subpixel	Line 86 Px. 102	Line 86 Px. 103	Line 87 Px. 102	Line 87 Px. 103	Contribution to View Window
e	h	f_i	f_j	e	$h + f_i + f_j + e$
b_i	k_j	c_i	g_j	b_i	$k_j + c_i + g_j + b_i$
b_j	k_i	g_i	c_j	b_j	$k_i + g_i + c_j + b_j$
a	m	d_i	d_j	a	$m + d_i + d_j + a$

Integrating the defined weighting of Figures 13 and 14 over each subpixel, we get the following as the upper left quadrant of weights:

0.000919	0.003021	0.005009	0.006214
0.003021	0.009937	0.016475	0.020439
0.005009	0.016475	0.027316	0.033888
0.006214	0.020439	0.033888	0.041736

Applying these numbers to the results tabulated just above, we find that a feature just covering subpixel "e" contributes 0.0702 to view window brightness, b_i contributes 0.0624, b_j contributes 0.0624, and "a" contributes 0.0551. Obviously Erdahl's condition is not met. Each subpixel should contribute 0.0625 to total brightness. If we envision an array of subpixel sized features with one such feature in each pixel, as the features move relative to the raster structure brightness varies by 0.0151, or 24.2%.

The weighting used above to illustrate the concepts was selected as a candidate for evaluation because it has a sound theoretical foundation and has given excellent results in tests[3]. Designate it as weighting "A" for subsequent discussion.

Weighting "B", Figure 16, is as close as you can get to weighting "A" while properly handling the temporal effects associated with field-rate update and interlace scan display systems.

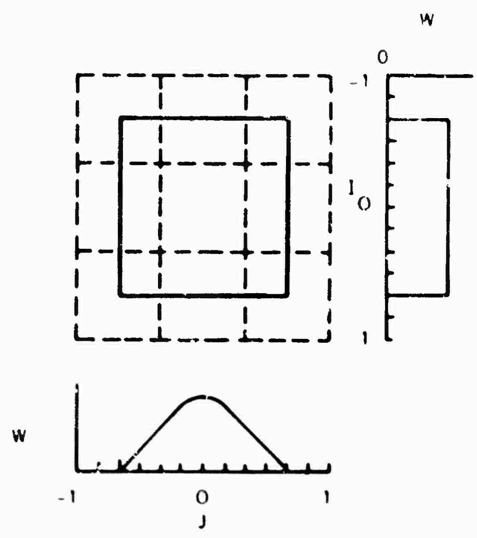

Figure 16. Weighting B. Horizontal: Sin J J Vertical: Uniform. ("A" modified to meet interlace temporal requirements)

Weighting "C", Figure 17, defines a pyramid over the region of the view window contributing to pixel video. It is the two-dimensional equivalent of the weighting of Figure 5, discussed in Reference 5.

Weighting "D", Figure 18, is weighting "C" modified to meet interlace requirements.

Weighting "E", Figure 19, defines a cone over the pixel. It is one which was proposed in Reference 2.

Weighting "F", Figure 20, is the one line by one pixel uniform weighting which has been the one most commonly used in real time systems.

Weighting "G", Figure 21, is a uniform two-line by one-pixel weighting. It was applied to a real-time laboratory system in 1977 and not only cured the problem of narrow faces disappearing, but also greatly improved other interlace artifacts such as comb effect and interlace-step effect.

Weighting "H", Figure 22, is two-line by two-pixel uniform, included to determine its effects.

The tests were made using a laboratory software scene generation system, with capability to implement any desired spatial filtering merely by inputting the desired set of weights. Part of the system is a time-lapse video disc recorder which allows sequences to be produced in slow time and viewed in real time.

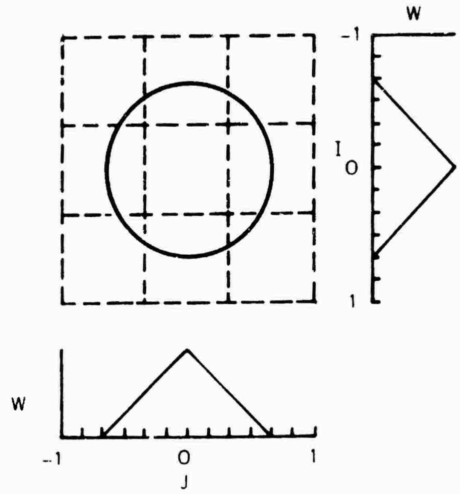

Figure 19. Weighting E. Cone

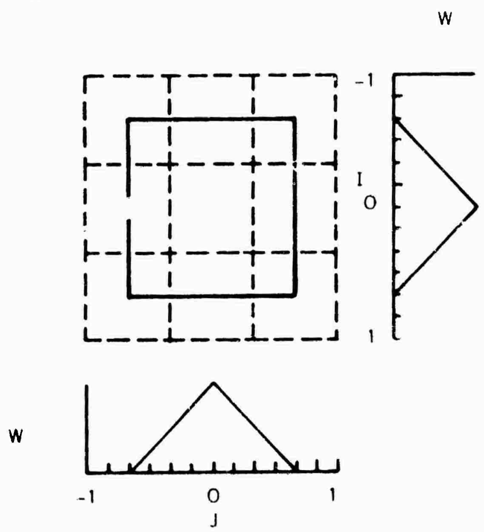

Figure 17. Weighting C. Pyramid

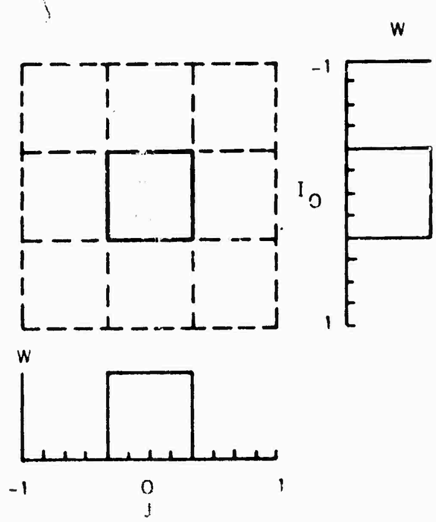

Figure 20. Weighting F. One line by one Pixel uniform

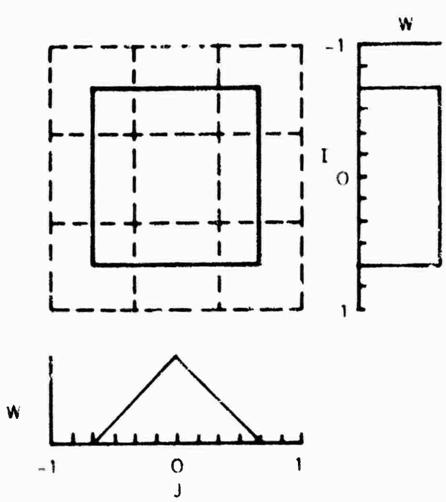

Figure 18. Weighting D. ("C" modified to meet interlace requirements)

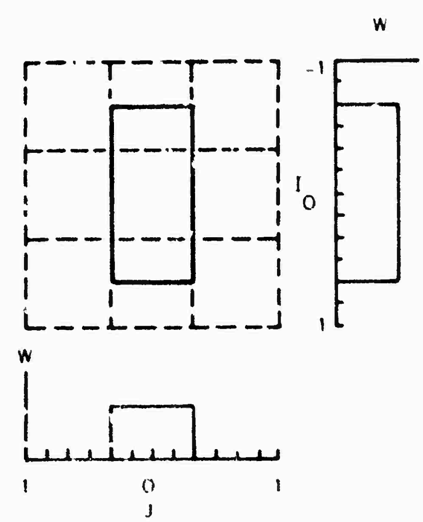

Figure 21. Weighting G. Two line by one pixel uniform

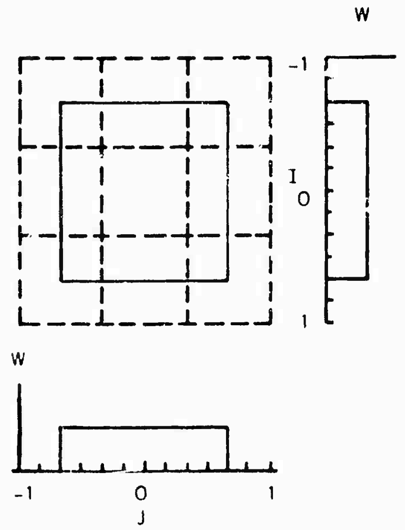

Figure 22. Weighting H. Two line by two pixel uniform

Limitations of Pure Oversampling

In pure oversampling, when the center of a subpixel falls inside a face, that subpixel's contributions to video for pixels are based on the color of that face. If we consider that an incremental movement of an edge may cause it to gain or lose one subpixel this will cause an abrupt change in pixel video on the order of 1/16 to 1/64 of the total contribution, depending on the specific filtering algorithm being applied. However, with certain orientations of edges (vertical, horizontal, 45°) an incremental change in edge position can cause it to cross the centers of a group of subpixels, causing changes in pixel video much greater than indicated above.

Figure 23 illustrates the type of problem this can lead to. The face bounded by the dashed lines has a brightness of 128 -- the background has a brightness of zero. To really make this worst case, weighting F, uniform one line by one pixel, will be assumed. Pixels 11 and 12 will have brightness of 96 -- in each of these pixels the face contains 12 subpixels. Pixels 13, 14, 15, and 16 will have brightness of 64, and 17 and 18 will have 96 again. Thus the scan line will have bright segments separated by a dim segment.

This effect is quite apparent on high sensitivity test patterns, but is rarely noted on actual training scenes. The cure is to designate subpixels belonging to a face based not on subpixel centers, but in such a manner that the total number of subpixels designated most closely approximates the total pixel area covered by the face. When properly done, this results in a system in which an incremental movement of an edge will result in imperceptable change in the scene.

Selection of Test Scene

If one wishes to make a valid comparative evaluation of a new computer, he would be well advised to apply it to benchmark programs which have been used on prior computers. Similar standardization would be of merit in spatial filtering investigation. In the past, different workers have applied their techniques to a variety of test patterns. Of these, the most sensitive appears to be the one used in Reference 4

> The pattern consists of triangles radiating from a common center. The triangles are defined as maximum intensity polygons against a black background. At the periphery of the pattern each triangle is one pixel wide and the space between neighboring triangles is four pixels

Each of the filter weights discussed earlier was used to generate scenes for evaluation using the described test scene

Scene Evaluation

The following comments are based on evaluation of 8 x 10 photographs of the test scene made with various filter weights. It is impossible to predict the degree to which the subtle differences will survive the process of size reduction and halftone printing -- which can itself add further Moire' effects to the scene.

Figure 24 shows the test scene without filtering -- each pixel gets either face brightness or background brightness, depending on the location of the pixel center. We look at this and chuckle. It is hard to believe that there was a time when all CIG was based on such processing. Not only that, but scenes produced in this manner are still providing training with proven transfer.

At the other extreme, filters A, C, and E give the best results for the static test scene, although it is known they would be unsatisfactory with a dynamic field-rate update system. There are only very slight differences among these three. Contrary to expectations, and based on the concensus of a number of observers, the conical filter, #E, Figure 27, gives the best results.

Filter B (Figure 28) can be thought of as Filter A modified to be satisfactory with field rate update and interlace smoothing. The horizontal filter shape determines the character of the near vertical triangles, and the necessary uniform vertical filter determines the character of the near horizontal triangles. The near horizontal triangles begin to exhibit aliasing at a greater distance from the center than the near vertical.

Similarly, Filter D (Figure 29) can be considered as Filter C or Filter E modified for temporal effects, and the analysis of the appearance is the same as that of Filter B.

Figure 30 shows Filter F, the easily implemented 1 line uniform weight filter that has been the standard in real time anti-aliasing. Figure 31, Filter G, is a uniform weight 2 line by 1 pixel filter. Figure 32, Filter H, is uniform, 2 lines by 2 pixels. These three exhibit very minor differences. As expected, the near-horizontal triangles look very much like those on the earlier uniform vertical weight filters.

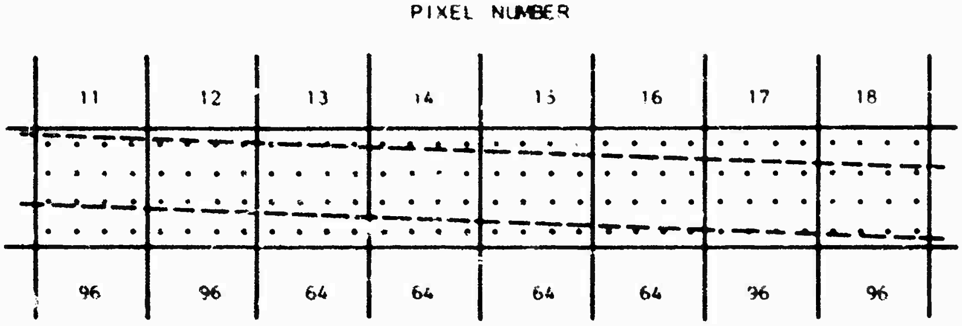

Figure 23 A Problem with Pure Oversampling

Training Area Test Scenes

A scene in a VTOL landing area data base was selected as representative of scenes encountered in training. A viewpoint was selected which placed a plant with numerous pointed leaves involving edges at a variety of angles near the viewer. Scenes were made using Filters E and F — the two extremes in quality (aside from the no-filtering case) based on the sensitive test scene. It was intended to print both; however, after a number of observers were unable to detect any differences, it was concluded this would be a waste of paper. The Filter E version is shown as Figure 33.

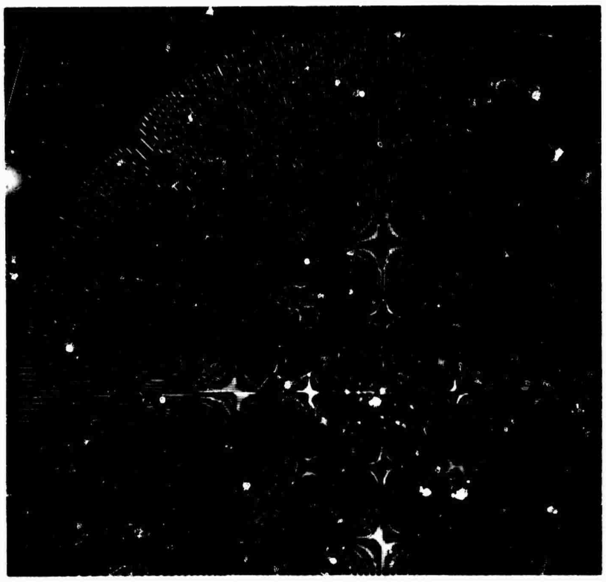

Figure 24. Test Scene Unfiltered

Figure 25. Test Scene With Filter A, Sin•J Sin•J J

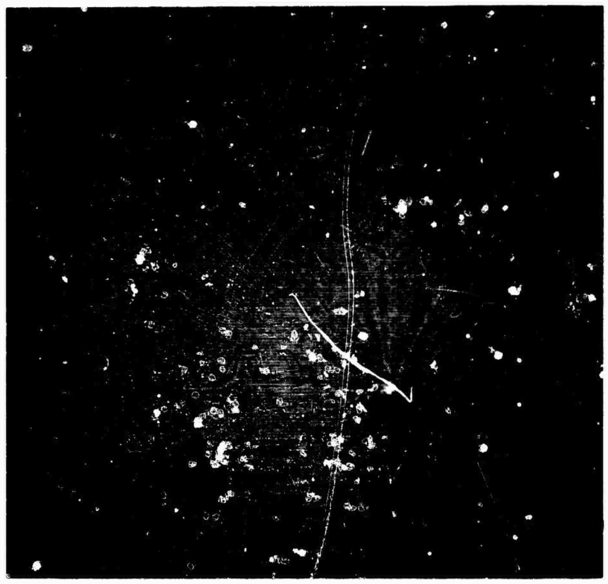

Figure 26. Test Scene With Filter C, Pyramid Weighting.

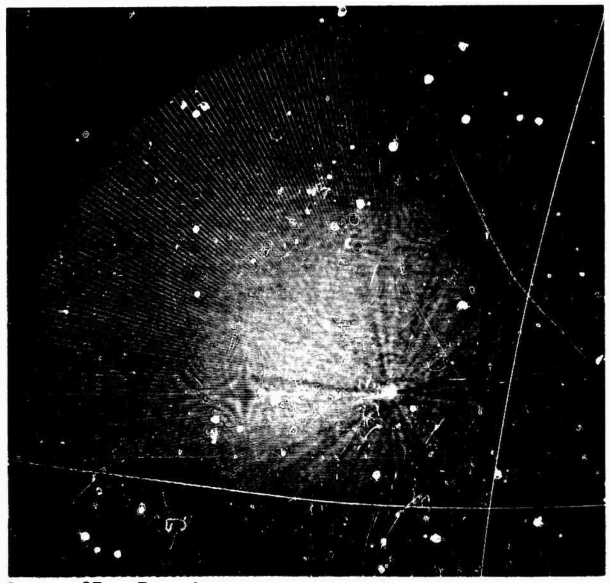

Figure 27. Test Scene with Filter E, Conical Weighting

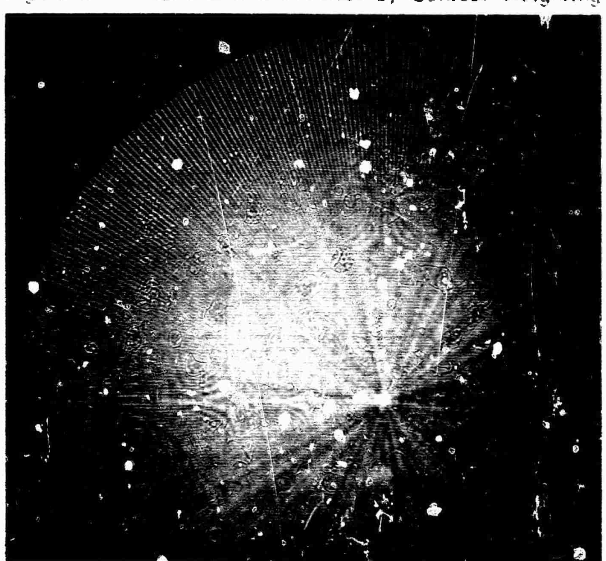

Figure 28. Test Scene with Filter B, Sine J J Horizontal, Uniform Vertical

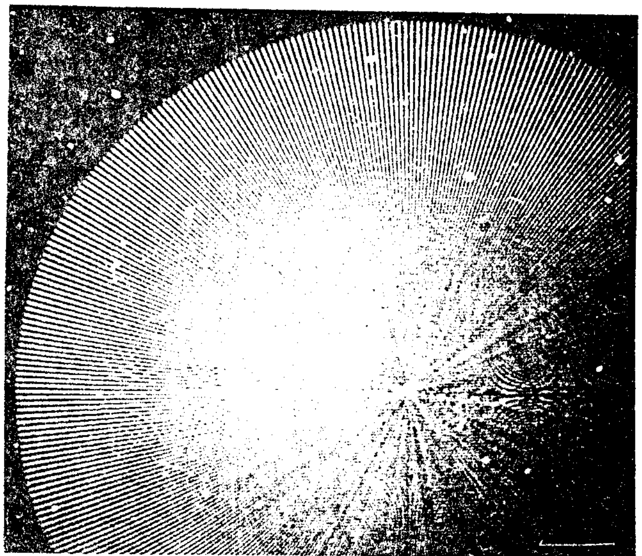

Figure 29. Test Scene with Filter D, Trangular Horizontal; Uniform Vertical

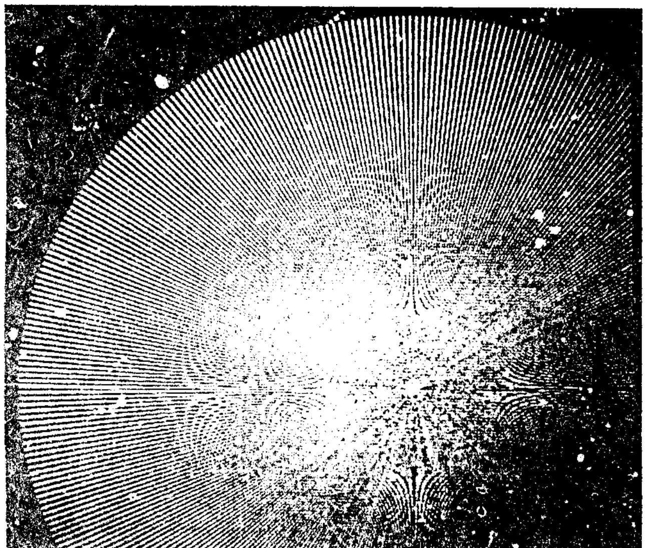

Figure 30. Test Scene with Filter F, 1 Line by 1 Pixel Uniform

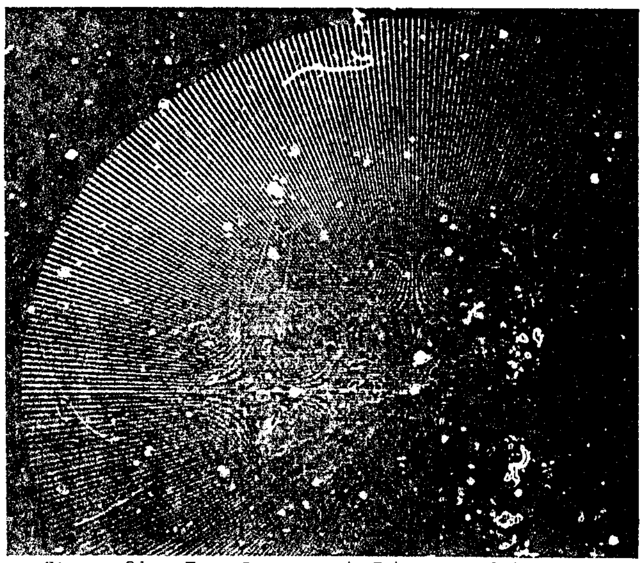

Figure 31. Test Scene with Filter G, 2 Line by 1 Pixel Uniform

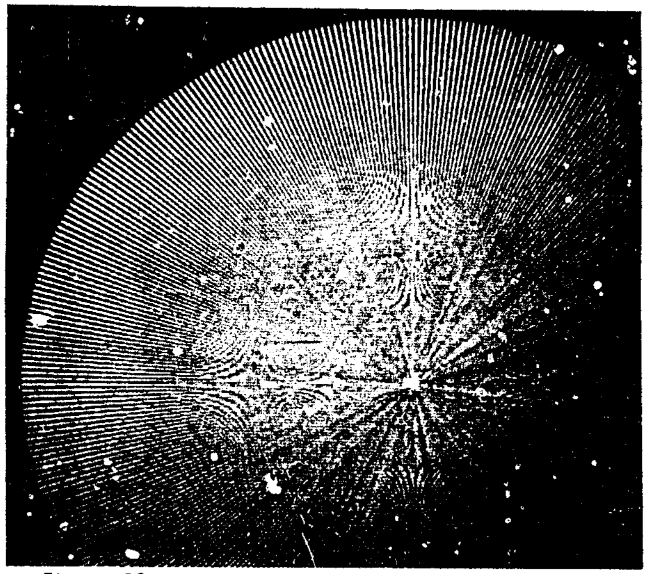

Figure 32. Test Scene with Filter H, 2 Line by 2 Pixel Uniform

CONCLUSION

There may be some doubt whether the topic of spatial filtering really calls for the amount of investigation and evaluation being applied to it. In Reference 6 Franklin Crow states: "... images made at low resolutions can be perfectly adequate if aliasing effects are sufficiently reduced." Whether or not one fully accepts this statement, there can be no doubt that a system with effective spatial filtering at one resolution will be functionally equivalent to a system with less effective filtering at a higher resolution. (Some of the early non-real time scene generation used 4000 x 4000 resolution with no spatial filtering and produced excellent results.)

One cannot automatically state that the most effective filtering known should be used. It may be significantly more expensive than the next most effective. It may exhibit its superiority on the sensitive test pattern, but show no discernable difference on training scenes. In evaluating the options, factors such as cost and system requirements must be considered as well as effectiveness of various filtering algorithms.

In establishing the fact that uniform vertical weighting is essential to eliminate temporal effects of raster interlace, this study removed one degree of freedom from those available to the filter algorithm developer. The evaluation scenes established that filters exhibiting significant differences when their different weightings were applied in two dimensions showed less significant difference when the uniform vertical weighting requirement was imposed.

The lack of detectable difference when filters at the extremes of the quality range were applied to typical training scenes indicates the importance of evaluating algorithms applied to the types of scenes to be used, and balancing any differences in results against the cost differences.

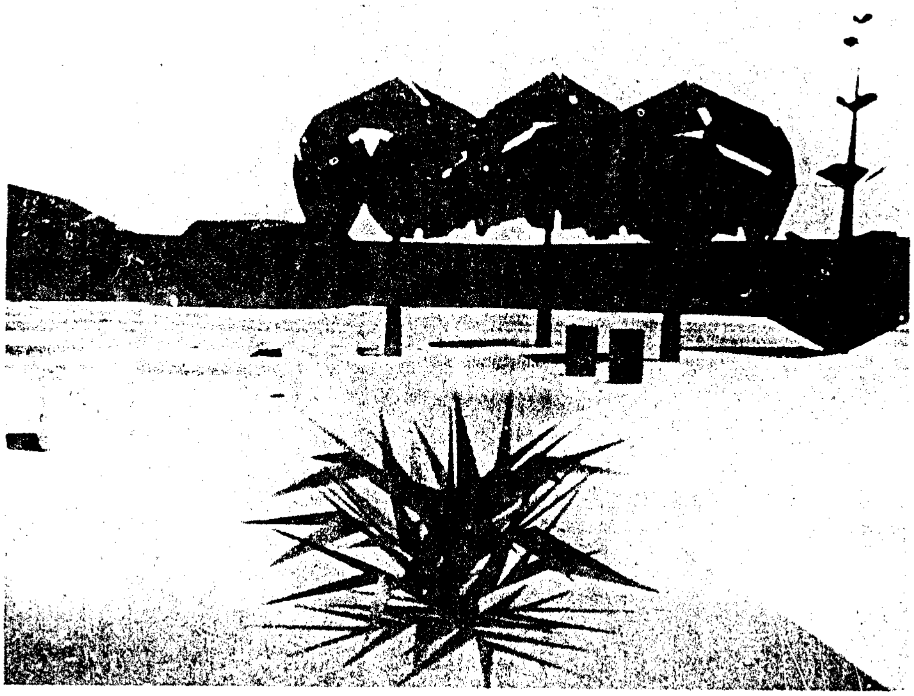

Figure 33. Training Scene Using Filter E

ABOUT THE AUTHOR

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TEXTURE IN A LOW COST VISUAL SYSTEM

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ABSTRACT

This paper describes the basic applications of texture in a low cost visual system. Texturing, as applied in this paper, is defined as the modulation of the intensity of a color on a surface. This gives a more natural appearance to the surface at a relatively low cost to the system. The use of texture to produce realistic movement, to create spacial effects, and to give the viewer a realistic feeling of perspective greatly improves the training capabilities of visual simulation systems.

HISTORY

Texturing plane surfaces in a visual system is not an entirely new concept. Blinn and Newell took the idea of mapping an image onto a smooth surface and extended it into mapping synthetically generated texture patterns and highlights onto surfaces.[1]

General Electric used texture patterns to simulate three dimensional objects in a system called the NASA Surface Generator. The output from this digital ground plane generator was one of the first systems to use the concept of a nested hierarchy of texture patterns.

Later, edge generation was added to the system to allow other surfaces to be modeled. The current low cost systems have had the ability to generate many surfaces using edge-face definitions, but are turning to texture as a way to increase scene complexity.

INTRODUCTION

The use of texture in a low cost system not only enhances the visual simulation of a scene for a viewer or trainee, but also allows the modeler much greater flexibility in generating data bases. As texture modulates the interior of the surface it is applied to, the modeler no longer has to use many surfaces to delineate specific features.

Low cost visual systems that are limited to several thousand calligraphic lights and several hundred surfaces have been successfully used for commercial and military pilot training.

These systems are effective for training activities that involve take-off, landing, and navigation, but because of the limited number of available surfaces, they are not able to produce the scene complexity necessary for advanced training. The problem has been to find a way to extend the training capability of these systems by providing a greater number of training cues, and while preserving the system's low cost.

The best solution found for a low-cost system was to provide a way of adding information to the surfaces used to make up a scene. A change in the intensity of the color across a surface provides a change in position cue, while the modeling and real-time cost is only one surface. This intensity change is produced through the addition of texture. The modulation of the intensity of a color on a surface is provided by table lookup of the intensity change in a memory whose address is a function of position on the surface. Figures 1 and 2 provide contrasting views of the same scene with and without texture.

Texture has been added to the NOVOVIEW SP3T visual system. Working with texture on this system has provided more information on the way models are constructed with texture, as well as the way texture should look and perform.

With the introduction of texture, there have been significant increases in training capabilities of the system. Advances have been made in such areas as low-level flight and over-water data bases that had previously presented special problems for low cost systems.

TEXTURE BUILDING BLOCKS

The basic texture building blocks are the texture patterns, the scale factor for each pattern, and color.

SP3T texture modulates the intensity of the color of surfaces in the ground plane, or in planes parallel to the ground plane. Individual texture patterns are stored in memories and addressed as a map of points. Each of these patterns can be combined together to modulate the intensity of a surface.

The Scale Factor

Data is generated in several different ways, each targeted towards a particular application. The surface description is expanded to include not only color information, but the combination of available patterns to be used to create the overall texture of the surface. The texture patterns are mapped onto the surface according to the scale factor specified by the modeler. The scale factor is used to determine the area on the ground that will be covered by one occurrence of the texture map.

The scale factor is used by the modeler in three different ways:

1. It sets the working altitudes the texture is to be used at.
2. It controls the repetitiveness of the texture patterns.
3. It controls the point at which the texture emerges into the scene.

For example, if a scale factor of 100 feet is specified for a texture pattern, then the pattern will be repeated every 100 feet. The modeler can specify the scale factor for each texture pattern stored in memory, and can combine the texture patterns to create other patterns. The careful selection of the scaling factor for each of the available texture patterns gives the modeler the ability to select the points at which more detail will emerge. This means the amount of detail in the scene will change according to the proximity of the viewer to the scene.

In the previous example, the texture pattern was given a scale factor of 100 feet. This repeats the pattern every 100 feet. However, if this pattern is combined with another pattern with a scale factor of 90 feet the combination of the two patterns will not repeat for 900 feet. And if this combination of patterns is combined with a pattern whose scale factor is 800 feet, the combination of the three patterns will not repeat for 7200 feet. The least common multiple of the scale factors is the point at which the combination of the patterns repeats. This is useful in minimizing the repetitiveness of texture patterns.

The Clamp Value

The amplitude of each texture pattern is modulated to provide control of pattern emergence according to the size of the pattern as it varies throughout the image. This function is based on computations that relate the scale factor to the image size projected into model space. The ratio of this distance to the scale factor is called the "clamp value". This value is calculated independently for each texture pattern. This method of antialiasing has proven to be more useful in controlling texture than any other method in use.[2]

For example, a surface that is textured with two texture patterns, one with a large scale factor A and the other with a smaller scale factor B, will have changes in the overall texture pattern at different proximities to the surface. As this surface is approached, the texture pattern with the scale factor A will be visible sooner than the pattern with the scale pattern B. A clamp value is calculated for each texture pattern's scale factor. The clamp values are applied to the patterns individually. This allows the final pattern to change and emerge as a function of the viewing perspective. The bandwidth of the scene is controlled to allow only the information that is free from unwanted aliasing to be viewed.

Texture Patterns

The modeler selects the texture patterns to be used in a particular data base. Texture patterns that are useful in one application may not be in another. For example, the texture map that is used to create a water pattern is derived from several sine functions, whereas grassy patterns are taken from a fractal-like function.

Fractal techniques have been used to create many "natural looking" scenes, as their application produces an effective randomness in the images.[3] The modeler should select the texture patterns based on the specific application of the data base.

The texture patterns can move in respect to other texture patterns, as well as to the surface they are modeled on. This motion is restricted to the plane of the surface, but the effect of the movement is appealing. Moving two or more texture patterns with respect to one another produces a wave motion useful for a sea scene or in grass, rotor wash in water, or dust trailing a vehicle.

Another variable in applying texture is the use of contrast in the texture pattern. Contrast is distinction between the dark and light areas of the pattern. The contrast of a pattern can be controlled to give patterns that range from subtle to very obvious. But too much contrast may result in an unrealistic scene that could alias inspite of the clamping function described in the previous section. Too little contrast can produce a pattern that is so subtle that it becomes ineffective. The over-all frequency spectrum of a pattern combined with contrast can yield a pattern that is less likely to require antialiasing.

Color

The color of a surface is chosen for its particular application. Texture patterns interact with the surface color, and can create greatly diversified scenes. The same texture pattern that is used to give the appearance of a grassy area on a green surface can be used to create a sand dune effect on a brown or tan surface. The appearance of a scene can be varied by the correct choice of color and the applied texture pattern.

Application of Texture Building Blocks

With the texture building block of pattern, scale factor, and color the modeler can apply texture patterns on surfaces giving height, motion, and closure cues. This gives the modeler on a low cost system more surfaces to use in creating man-made structures or non-ground plane natural objects.

These building blocks have been used to generate data bases that range from water to desert and grass to clouds. Figure 3 is an example of the application of texture in producing a sea scape. The waves are made up of two texture patterns at scales of 271 feet and 1023 feet. These values were chosen to provide for working altitudes of 100 to 1000 feet. At an altitude of 1000 feet, the blue sea color is broken up to provide motion cues. As a pilot descends below this altitude, the smaller pattern emerges, providing closure cues for him. The effect of the emergence of the texture can best be demonstrated on the visual system itself, or in a motion picture. Figures 3, 4, and 5 show the emergence of the texture as the position of the observer changes in three static pictures. The ship is shown to provide a distance reference.

The first view, Figure 3, shows a very large texture pattern from an altitude of 1000 feet. Figure 4 shows the texture as the second pattern is beginning to become visible at about 250 feet. Figure 5 shows the texture patterns from a height of 50 feet, where the viewer can no longer see the effect of the larger texture pattern.

The scale factor is used to specifically tune the data base for its intended application. The scale factors used for a high altitude flight path would be different than those used for low level flight or for maritime applications. The scale factor is incorporated into the data base during the design process and gives a system the flexibility to be used for many design applications.

APPLICATION OF TEXTURE IN DATA BASES

The addition of texture to the NOVOVIEW SP3T product line has solved many of the traditional problems that face data base designers; specifically how to incorporate the scene complexity needed for speed and height cues, and at the same time provide enough real world features to make the date base usable and recognizable. While the use of texture greatly simplifies some design areas, there are several new parameters associated with texture implementation that require decisions to be made early in the design process, and that may require possible tuning throughout construction. These parameters include the design or selection of the texture patterns, the size of each pattern, and the height and dynamics of each selected pattern.

As with all other elements of the data base, the texture features must be selected for the intended training requirements. For example, if helicopter take-off and landing training is the intended application, then a texture pattern designed for use at 10,000 feet would be wasted on the low altitude flight simulation of the helicopter.

The texture patterns can be selected only after the use of the data base has been established. In the NOVOVIEW SP3 system, the user can choose a total of four texture patterns from a growing library constructed by the supplier on an in-house computer and frame buffer facility. The process of textureselection should include the end-user, whenever possible, to meet the specific needs of the data base design.

The choice of the texture patterns must be evaluated with the combination of the available scale factors and their application to the various colors to determine what is most suited for the particular training needs. Fortunately, system architecture readily allows for the substitution of different patterns or alterations in pattern size during the construction process.

Once an initial set of texture patterns has been selected, the allocation of system resources can begin. Using texture for natural features and reserving the edges and faces (and light points) for cultural objects is the standard approach. The classic example of this configuration is the ship in Figure 1, where all of the system capacity except the sky and water surfaces is dedicated to the ship and wake.

Many applications of texture are not as clear cut as the ship example. With an extensive use of texture in sky and cloud features, a pilot will still require a frame of reference. This could be provided by cross checks with airspeed and altimeter instruments that would take place in the real aircraft. The advantage of texture is that the frequency of these cross checks is much closer to real world flying conditions. The frame of reference can be established by having items of know size and orientation along the flight path. When system capacity allows for it, reference features should be included in the data base design.

Natural Scene Elements

Texture's most obvious application is to large homogenous areas such as ocean, desert, snow, and sky/cloud scenes. With these fairly simple cases, there are still considerations to take into account. If a pattern is too small or has too much contrast, the repetition of the pattern can become obvious and distracting. This can be solved by tuning the scale of the pattern or choosing a less regular one, such as shown in Figures 6 and 7.

Attention must also be given to the texture chosen, so that it doesn't supply too many cues. The real world task of flying at low altitudes over large homogenous areas like water or snow can be very hazardous because of disorientation and optical illusions. If the textures creates a scene that is too solid, negative training could result. The dynamic capabilities of the texture can be used to avoid this problem. An effective approach is to move each of the texture maps independently. In the case of an over water flight, the same "wave" pattern can be loaded into two of the available texture maps. The patterns can then be moved in opposite directions at the same speed. The constant interaction between the two patterns creates a heaving effect. This same method can be used to produce blowing snow or sand.

Sky and cloud decks are also obvious applications of texture. On clear days, the sky will normally have some clouds that can provide turning and pitch cues when the ground is not visible. A subtle texture pattern applied to the sky and placed at an altitude high enough to not be penetrated has a realistic appearance and can provide turning cues. An example of this is shown in Figure 8. Cloud layers, as shown in Figure 9, require a more definite pattern. Some of the available texture patterns could be applied slightly above and below the selected cloud ceiling or cloud top. This provides parallax cues that have a three dimensional appearance. The ground texture may be simultaneously used above the horizon with a different (usually larger) scale factor.

When selecting ground patterns, their application to the sky and clouds may be a consideration

Texture can also be effectively used on small areas. As shown in Figure 10, the texture pattern is used to simulate a metal mesh. This pattern is elevated to provide effective parallax cues when viewed with other patterns in the surrounding area, such as the sea surface pattern.

Cultural Scene Elements

The use of texture on man-made or man induced scene elements is not as frequent as on natural ones. When applied to cultural objects, it tends to be used on relatively small areas. Figure 11 shows the use of a small scale fractal pattern to simulate the surface and expansion cracks on a concrete runway. This is an effective speed cue during landing and taxi training. Although this is a useful application for texture, these patterns are limited to the small areas they were designed for. Also, such small areas are more likely to alias when close to eyepoint. The interaction of the pattern size and the clamping function is used to maintain a solid scene. Because of this, in an application where several different small patterns are required in different parts of the data base, a management technique may be used that brings in a new pattern as each area is approached. This allows the combination of several patterns to be applied to the overall scene, including the sky, while applying only one pattern to small dedicated features.

SUMMARY

The overall implementation of texture in the NOVOVIEW SP3T has allowed experimentation in areas not previously associated with low cost systems. The use in scene elements such as smoke, dust clouds, and ship wakes are examples of the successful application of texture. The application of moving texture on static surfaces, or static texture on moving surfaces, and texture moving simultaneously provide a wide variety of effects. Different texture patterns, static or dynamic, when applied to adjacent surfaces of the same color, produce results similar to the shading effects that are associated with more expensive systems.

The addition of texture generation capability to a low cost system greatly increases the application range of that system. Not only does texture enhance the simulation properties of the system, by producing images that more closely resemble terrain, sky and cultural objects, but these enhancements are at a relatively low cost to system overhead. With the antialiasing properties available, texture allows the proper emergence of detail, making the closure to objects more realistic.

Originally, texture was conceived as a way of breaking up surfaces to provide the viewer with more information about surface contours, but the texture generating capabilities achieved through experimentation and problem solving have proven texture to be a much more valuable tool.

The application of texture, within the structure of a low cost system, provides the end user with a data base that simulates more natural appearing scenes and provides extensive training cues not previously available in such a system.

ACKNOWLEDGEMENT

We wish to thank Evans and Sutherland Computer Corporation and Rediffusion Simulation, Inc. for their support in the delvelopment of this paper. While it is not possible to mention all of the people who have worked directly or indirectly on texture and the preparation of this paper, we must thank Lynn Orchard for her help in editing and preparing this paper.

ABOUT THE AUTHORS

Philip Skolmoski has been with Evans and Sutherland since 1974. He is currently the supervisor of Novoview software development. He was responsible for the Novoview texture development describing the mathematics and architecture of the system. He supervised the hardware and software development of SP3T. Mr. Skolroski received his bachelor's degree in Computer Science from the University of Utah in 1973, and was a teaching fellow in that department until employed by Evans and Sutherland.

Michael Fortin has been associated with data base development and production at Rediffusion Simulation since 1974. He holds a bachelor's degree in Mathematics from Florida State University, and served seven years as a Naval Aviator, flying light attack aircraft.

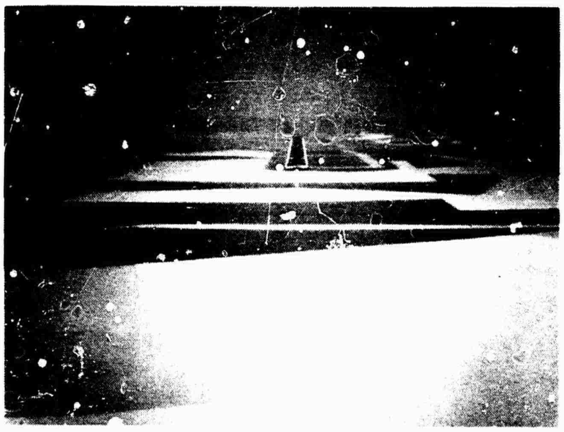

Figure 1 - Norfolk without Texture

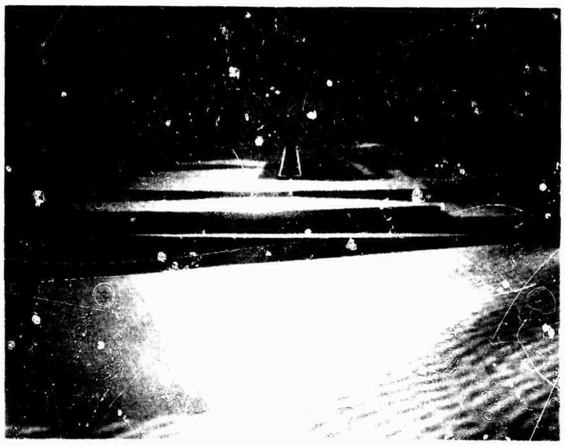

Figure 2 - Norfolk with Texture

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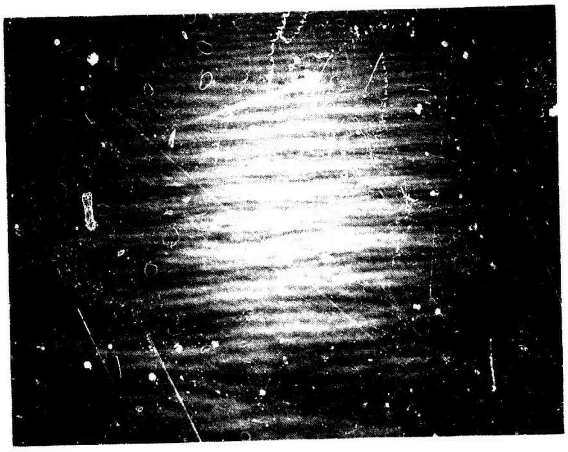

Figure 3 - Ship in Textured Sea at Altitude of 1000 Feet

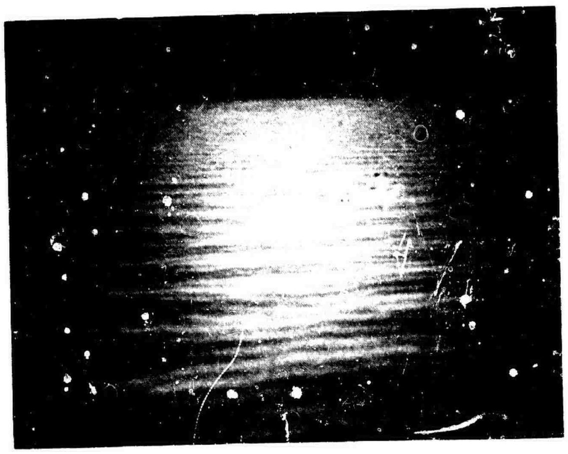

Figure 4 - Ship in Textured Sea at Altitude of 250 Feet

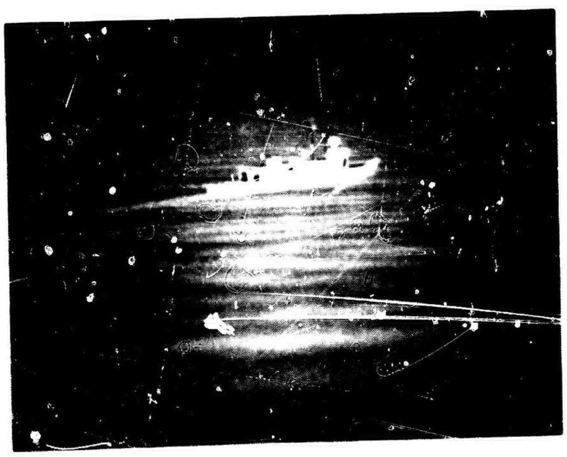

Figure 5 - Ship in Textured Sea at Altitude of about 50 Feet

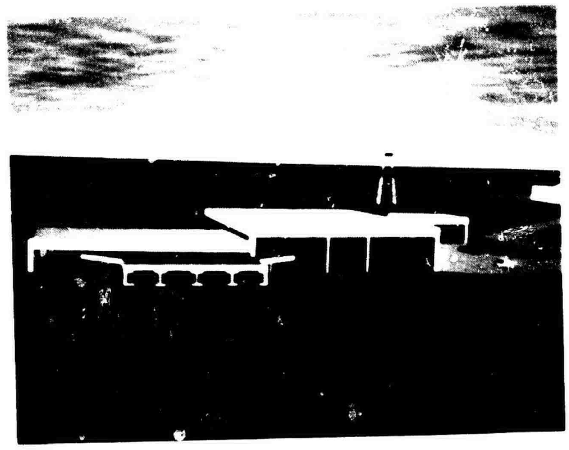

Figure 6 - Conrow Airport with Grassy Texture

Figure 7 - Desert Scene with Tanks

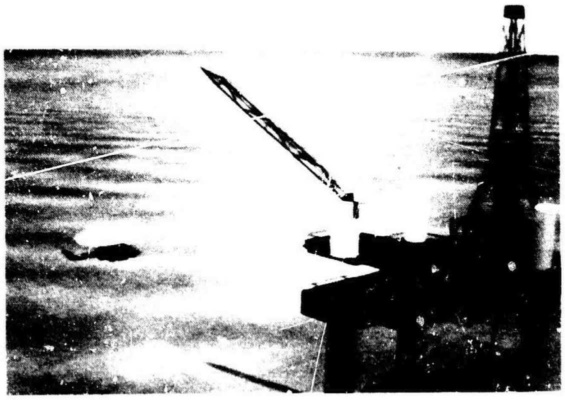

Figure 8 - Texture on Water Surrounding an Oil Rig

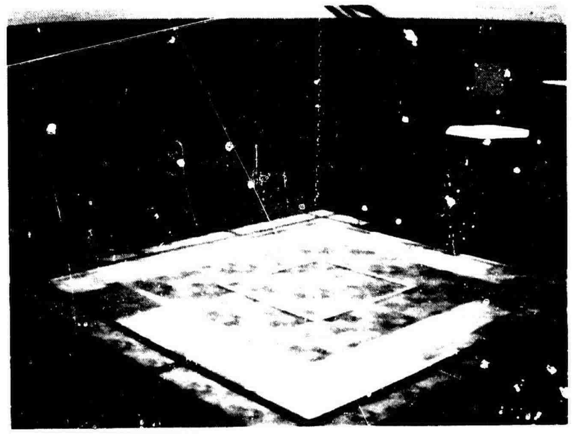

Figure - 10 Texture on Two Heights; the Water and the Wire Mesh

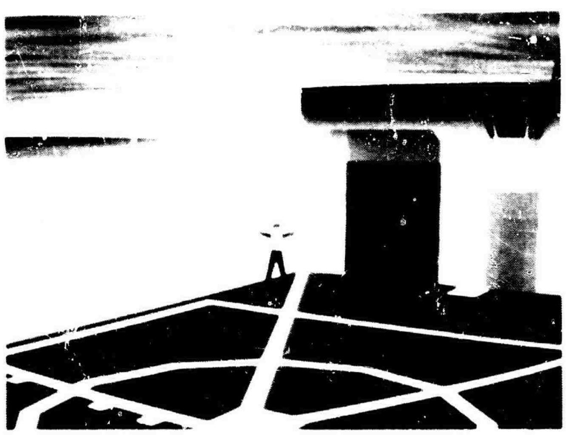

Figure 9 - Cloud Texture Above Landing Pad on Ship

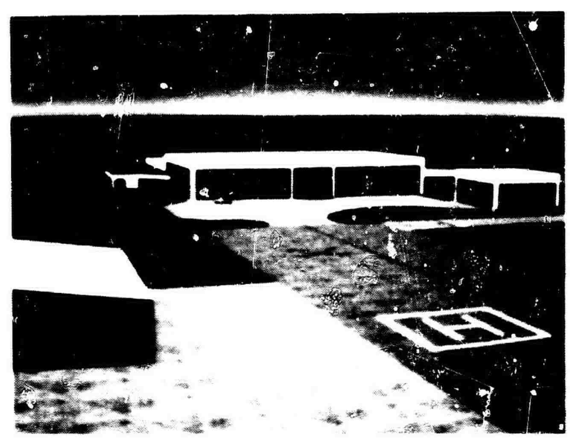

Figure 11 - Cement Texture with Runway Cracks

COMPUTER GENERATED/SYNTHESIZED IMAGERY (CGSI)

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ABSTRACT

Feasibility has been demonstrated for a hybrid simulation approach which merges two technologies, Computer Generated Imagery (CGI) and Computer Synthesized Imagery (CSI), to form Computer Generated Synthesized Imagery (CGSI). This approach holds promise as a cost-effective, attainable method of providing real-time, high detail imagery for visual and/or other sensors, such as FLIR. A videotape for a nap-of-the-earth flight was generated, demonstrating the fidelity and mobility that can be achieved using this CGSI hybrid approach. A description of the approach will be provided along with selected video frames. Critical features which were demonstrated include: merging of the two technologies, vertical movement for target acquisition and landing, horizontal movement towards and away from objects, dynamic occulting of 3-D objects, dynamic smoke and dust, and color visual and IR imagery.

INTRODUCTION

The advanced development and increased use of such sophisticated sensors as: thermal imaging; low light level TV (LLLTV) and imaging radar have significantly expanded the capabilities of military platforms. Sensor technology developments have contributed both to safer and more effective operations and tactics. These gains in weapons system capability, however, can only be fully realized through effective training programs. This training is more difficult because, perceptually, sensor imagery, such as infrared, is novel to observers and therefore more difficult to use and interpret. This problem is compounded under high data rate workload conditions such as low-level flight. Training and exercising with the actual sensor systems in the real environment are certainly valuable training and contribute to the effective employment of the sensor system in each mission phase. However, the cost and availability of fuel and other training resources, combined with risk, have resulted in the reduction of actual platform training hours and, consequently, the opportunity to exercise the actual sensor systems. In light of this situation, more attention must be directed to the development and use of simulators. One of the challenges of simulation today is the effective, coordinated simulation of advanced sensor systems for training high data rate workload conditions such as low-altitude flight missions, nap-of-the-earth (NOE) and shipboard operation. In addition, a highly desirable factor in any sensor simulation approach is the ability to correlate with an out-the-window visual scene.

To achieve the required level of simulation, designers must consider a variety of factors including the aircraft itself, its mission, the sensor system, and the environment in which the system will be employed. In addition, there are other factors related solely to the actual simulation of sensor operation which must be considered.

Hybrid system concepts such as Computer Generated Synthesized Imagery (CGSI) offer near-term solution for simulating sophisticated sensors and correlated visual sensor imagery. Because of the high potential pay-off from the real-time implementation of CGSI, NAVTRAEQUIPCEN, with support from PM TRADE, has funded Honeywell's Systems and Research Center to provide a non real time demonstration of CGSI for a NOE flight and a design for real time implementation of CGSI. This report summarizes the results of the effort.

COMPUTER GENERATED SYNTHESIZED IMAGERY

This section describes the merging of the Computer Generated Imagery (CGI) and Computer Synthesized Imagery (CSI). CGI uses the computer to generate imagery from a data base. CSI uses the computer to insert targets/objects in real-world pictures. CGI provides excellent control of a scene to be constructed and displayed for interaction in a simulation environment. However, the fidelity is low, and as a result, realism in the displayed scene is poor. CSI is just the opposite. Fidelity is high, but control over scene construction is restricted. Figure 1 represents the fidelity/viewpoint flexibility of CGI and CSI and the resultant CGSI (Computer Generated Synthesized Imagery).

Figure 1. A Computer Generated Synthesized Scene

Contributions from Computer Generated Imagery (CGI)

The strength of CGI is its ability to generate surface representations. A real or artificial surface can be measured to get elevations at specified points, usually at intersections of a uniform grid. The surface can be constructed in a computer by connecting the sample elevations.

In addition to realistic surface representations, CGI offers control over the placement of objects on the surface. Since the data of elevations is usually provided with a uniform grid, the placement of other objects can be specified on this same grid. Trees, rocks, shrubs, houses, and roads can all have their positions defined in the data base grid system.

Correct illumination and perspective are the final two major contributions from CGI. Correct illumination is achieved by finding the surface normal for each pixel displayed. This normal is used along with line-of-sight and the normal from the illumination source plus amibient intensity and haze factors to compute pixel intensity values. Correct perspective is achieved because the distance is a significant variable in the perspective transformation.

Weakness of CGI

Although the position of an object can be accurately specified, correctly illuminated, and displayed in correct perspective, the fine detail of an object cannot be realistically represented. The current state of the art in CGI object representation is such that objects appear cartoonish. Some scene elements, such as barren terrain, sand, and clouds, can be represented more realistically than highly detailed structured objects like trees and grass.

Contributions from Computer Synthesized Imagery (CSI)

CSI uses photographs of real scenes. The objects in the scenes are not represented individually; nor is the scene modeled by elevation profiles. Usually the scene is held static, while single objects, like aircraft or tanks, move within the scene. The path followed by the moving objects is carefully laid out. In each frame, object occlusion is resolved by deciding which objects are in the foreground and which are in the background. This is a manual procedure.

The strength of CSI lies in its use of photographs. With currently available video equipment, the photographic data can be manipulated in a manner previously considered impossible. Individual photographs can be stored on a video disc, along with hundreds of other photographs. Access is controlled by an index just as with digital data stored on magnetic disc. Thus, a frame can be constructed by calling up individual photographs and merging them in a frame buffer.

Weakness of CSI

The high-fidelity CSI scenes are limited to the viewpoint of the camera. That is, one cannot drive through a scene unless a series of through-the-scene photographs is used. For any reasonable size gaming area, the number of through-the-scene photographs become prohibitive. For limited applications with fixed observers, CSI may be sufficient.

CGSI: The Merge

CGSI combines the best features of both techologies: CGI and CSI. A scene is constructed by placing individual high-fidelity CSI objects on a specified CGI surface. A CGSI scene is constructed much like a CGI scene. The surface elevations and object locations are laid out on a uniform grid. The individual objects used in the scene are transformed for perspective and size. This includes size, position, rotation, warp, and intensity transformations on the image. The surface may be a CGI texture or a series of CSI surface inserts. The scene is constructed by placing the farthest object first and continuing with overlays until the nearest objects have been placed. The CGSI scene may be constructed with imagery from any portion of the spectrum—visual, infrared, millimeter, or radar frequencies.

HOW TO BUILD A CGSI SCENE

This section demonstrates the construction of a typical CGSI scene through eight steps. After the eight steps are completed, the resulting scene is provided to the video monitor. This process is repeated at the 60 Hz field rate.

The construction of a CGSI scene begins with the surfaces, ground, and/or sea and sky. The sequence continues with the addition of objects, both small and large. The objects may be trees, rocks, bushes, houses, roads, lights, vehicles, ships, docks, airplanes, etc. Finally, the special effects are added which include smoke, dust, clouds, and shadows.

Sky (Figure 2)

Sky is added in segments over distant background. By breaking the sky into segments, peaks, and valleys form the skyline shown. In this example, the sky was broken into five segments. In general, the lower edge of the segment does not need to be straight, but may be curved or jagged to simulate rolling or sharp hills or mountains. The individual segments are warped based upon minimum and maximum data base elevations and upon viewpoint.

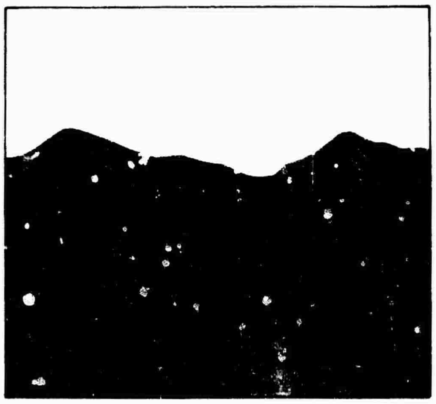

Figure 3. Textured Surface Scene

Road Scene (Figure 4)

The surface library may also contain special surfaces such as roads, streams, and ponds. In this example, roads in the data base library were warped to fit the screen coordinates. This scene also contains four textured surfaces.

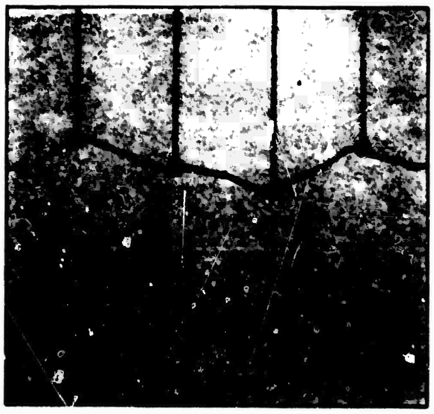

Figure 2. Sky Scene

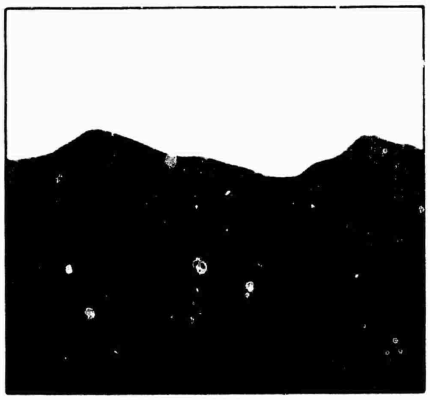

Figure 4. Road Scene

Textured Surface Scene (Figure 3)

Textured surfaces are also added in segments to form the foreground surface. The untouched region between the sky and foreground forms the distance background. Stored textured surfaces warped to fit the screen coordinates of the surface polygons, are then added to the screen. The intensity of the surfaces is varied based upon the range or other parameters

Small 2D Objects (Figure 5)

Small two dimensional (2D) objects, less than 1/16 of the scene's area, are added. Most natural objects such as trees, bushes, and rocks may be represented from one side. These are called 2D objects. Objects which cannot be represented from one side such as houses, tanks, ships, etc. are referred to as three dimensional objects (3D). Small objects are processed by less ex pensive processing hardware/software than large objects and surfaces. During the flight through a scene, the 2D object will be handed off to a large 2D processor when it occupies more than 1/16 of the area of the scene.

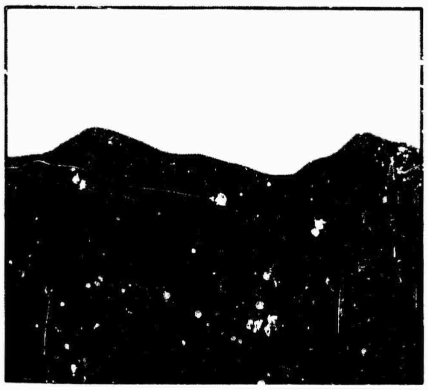

Figure 5. Small 2D Objects

Multi-View Object Scene (Figure 6)

The tank is an excellent example of a multi-view object. Multi-views of the tank are stored and the correct view, based upon the tank path, elevation, and observer's viewpoint, is used in constructing the scene. The tank may be moving and may be very large.

Figure 6. Multi View Object Scene

Multi-Surface Object Scene (Figure 7)

The house is an excellent example of a multi-surface object. The house is separated into three surfaces, two roof segments (one if both sides are identical), two ends, and two sides. The individual surfaces of the house are warped from a normalized view to the perspective dictated by the screen coordinates and then joined together. Images of this type may be constructed for enemy objects if intelligence information is presented.

Figure 7. Multi Surface Object Scene

Large 2D Object Scene (Figure 8)

Large 2D objects typically occupy more than 1/16 of the scene's area. These objects may be expanded so that an object will cover more than the entire surface of the screen.

Figure 8. Large 2D Object Scene

Special Effects Scene (Figure 9)

Special effects are used for translucent surfaces which include clouds, dust, smoke, and shadows. A mask controls the transmission functions and a second input word controls the intensity and color.

Figure 9. Special Effects

Complete Scene (Figure 10)

This completes a CGSI scene.

Figure 10. Complete Scene

CGSI SYSTEM OVERVIEW

Figure 11 is a functional overview of a real-time CGSI system.

Data Base Construction

The data base consists of two very different types of data: the object library and the gaming area.

The object library contains images of objects and surfaces, and transmissivity masks of special effects from one to many bands of the spectrum. This allows the simulation of not only the visual domain, but also infrared, millimeter and radar frequency sensors. The object library may also contain a mixture of 2D and 3D images. The images may contain a variety of day night and diurnal conditions. The object library consists of many actual high-fidelity images taken in the real world from sensors and stored in a photographic manner. In constructing a high fidelity object library, images from individual real-world elements, highly accurate models, artist drawings, photographs of enemy devices, etc., are restored (correct edge roll off) to form "near-perfect" images. This is achieved by operator and machine controlled thresholding (dropping out the background) intensity corrections, realistic color control and perspective normalizing. Ground contact and height reference points are also added. The "near-perfect" objects, surfaces, and special effects are stored on a rapid access and high-speed data rate media.

The gaming area data base provides the information necessary for placing the contents of the object library, objects, surfaces, and special effects on a grid or gaming area. The objects may be placed by an operator or in a random manner by the computer. The objects in the library may be either stationary or capable of movement.

The output of this function determines ***"What is in the scene."***

Vehicle Simulation Computations

The vehicle simulation computations, based upon the vehicle math model and control inputs, determines the locations and viewing direction of the visual or sensor system for the primary vehicle. In addition, computation may be performed on secondary vehicles based upon vehicle models and selected paths. The output of this determines, ***"Where am I?"***

Systems Interface

The I/O of the vehicle simulation system and I/O of the CGSI system must interface in an efficient manner. The communication subsystem is a bi-directional link and buffer interfacing the two systems. This function is the handshake and data flow between the systems, ***"Communications."***

Field of View (FOV) and Coordinate Transform Computations

The FOV processor determines the presence of objects, surfaces, and special effects in the scene under construction. The output of a transformation matrix (V) converts real-world coordinates to screen coordinates. This data from the transformation matrix permits rapid testing and determines if all or any portion of the objects, surfaces and special effects are present in the scene. To avoid testing for the presence of all the objects in the data base, a "smart" algorithm tests only those objects or surfaces which are in the proximity of the scene. The FOV processor maintains a list of objects in the FOV and their object, surface or special-effect channel assignment. The function of the FOV computer is to determine, ***"What can I see?"***

Controllers – Object/Surface/Special Effects

The controllers fan out and process the control functions generated during the FOV computation. The processed control functions are passed to the object surface special effects processing channels. The main functions performed by the controller are the transform of gaming area corrdinates to screen coordinates, range from the vehicle to each object in FOV, intensity of each object based upon range, object identification, and commands to the object library base for the retrieval of the correct image data. The function of the controller is to ***"Fan out FOV data and generate precise control data."***

Object/Surface/Special Effects Library

The library stores the images used to construct a scene. The controllers command the selected images

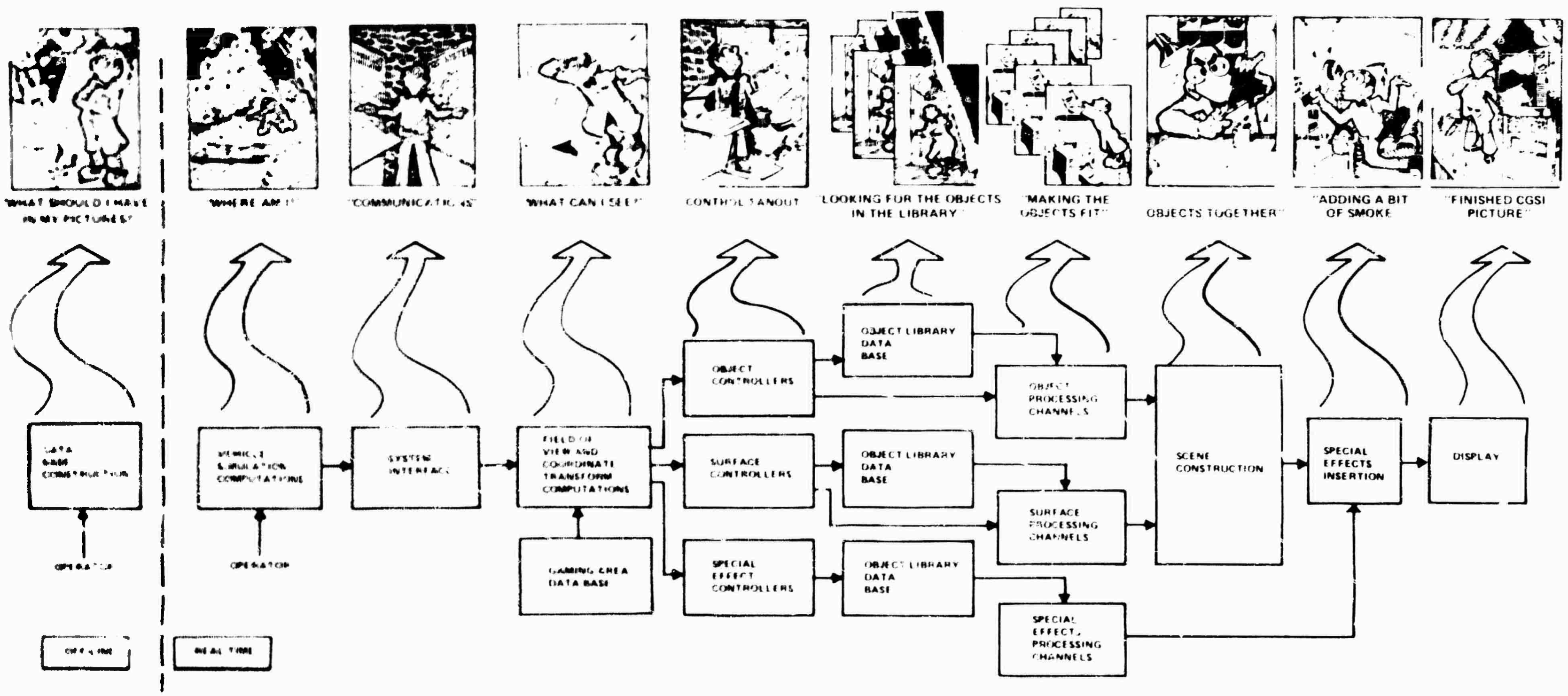

Figure 11. CGSI Functional Overview

which are passed to the processing channels. The function of the library is to "*Provide the correct image upon command.*"

Object/Surface/Special Effect Processing Channels

The individual processing channels pipeline processors process one object, surface or special-effect per channel. All the processing channels operate in an identical manner; large object, small object, surface or special effects. Each processing channel modifies objects, surfaces, or special effects from the object library by the transformation specified by the control functions. That is, the object, surface, special-effects processing channels change a stored image (normal perspective) to scene conditions (screen coordinates) by changing image, position, size, rotation, and warp. Image intensity is modified based upon range and object type. The function of the parallel pipeline processing channels is to "*Modify each object, surface, and special effect used in the scene.*"

Scene Construction

The scene construction module takes the individual image from each processing channel, separates the image from the background, and assembles the scene based upon range. Near objects occlude more distant objects. The high-frequency edges generated by assembling a scene from individual images are smoothed by a Gaussian function. This operation matches edge and internal frequencies.

This function receives range information from the two object controllers. This range is used to determine whether or not a particular object is in front of, or behind other objects in the scene. If the particular object pixel is the closest occupied pixel in the scene, then it will be the pixel displayed. This may be termed a "*nearest*" algorithm.

The scene construction function accepts video inputs from each video channel, and from a background level source defined by the FOV computer. This function outputs real-time video signals to the special effects.

The digital scene construction function contains the following subfunctions: 1) object channel combination, 2) scene intensity adjustment to accommodate scene wide intensity corrections, and 3) smoothing to compensate for object to object and object to background boundaries. The function of the scene construction module is to "*Assemble the picture.*"

Special Effects

The translucent special effects are added after the generation of the scene. The special effects module adds the special effects based upon range. Special effects, such as smoke, or dust, may occur ahead of, or behind images in the scene. The intensity masks stored in the object library and processed in the special effects processing channel control the transmissivity of the special effects. The intensity value input controls the intensity color of the special effects: the black smoke and white clouds. The function of the special effects module is to "*Add dynamic or static translucent effects.*"

TECHNOLOGY OVERVIEW

Figure 12 presents a hardware software overview. It shows that:

1. Most of the hardware exists as a complete subsystem or at the card level.
2. The system does not contain large amounts of software.
3. The system has common components; the same hardware and software is used for controlling surfaces, objects, and special effects.
4. The system is modular. The technology can be configured for many different applications by adding or subtracting the modular components.
5. The input images are real.
6. The real-time requirements of 30 frames second and 100 millisecond transport delay are achievable.
7. The key components in the system are the object surface special effects processing channels.

Object/Surface/Special Effect (OSSE) Processing Channel Hardware

Because of the extreme importance of the OSSE processing channel hardware it is discussed in greater depth.

To obtain the correct intensity, color, image, size, location, rotation, and perspective the following functions are performed on the library data.

a. A high speed (approximately 100 nsec samples) analog-to-digital converter converts the object image to a digital format. The digital format has 512 pixels per line, 480 active lines (525 total) and eight bits per pixel (256 gray shades).

b. A high speed memory card accepts the digital data in either the X or Y axis. The axis and direction of loading is dependent on the rotation of the image. The data is loaded to minimize pixel compression during the processing passes. Rather than rotate an image 60 degrees which may result in some image loss, the data is loaded in the perpendicular axis (at 90 degrees) and rotated 30 degrees. This memory card also holds the object image for processing when the optical disc controller is selecting a new track (image). This card may be omitted if the objects are stored on the disc in 90 degree increments or if the rotations are less than ±45 degrees.

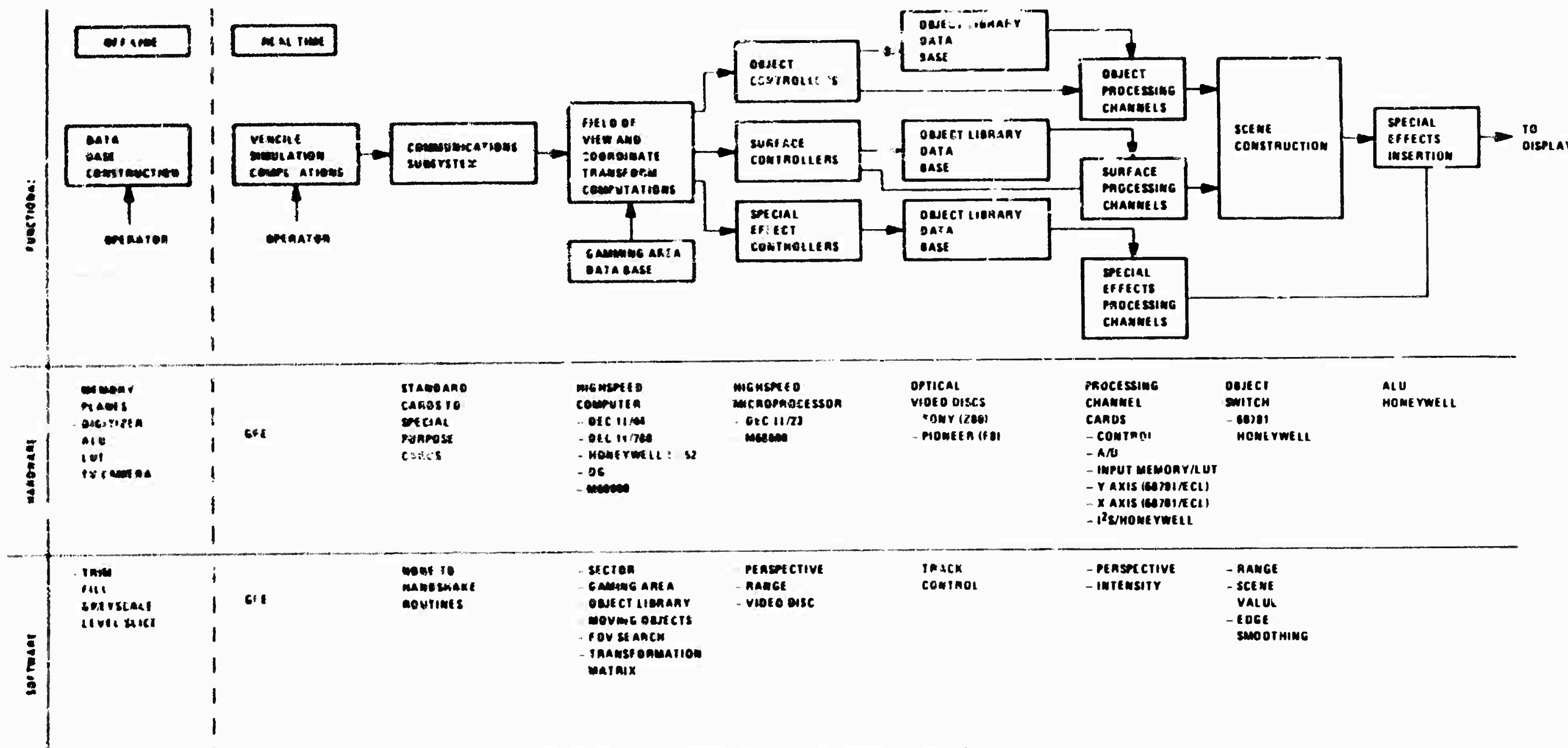

Figure 12. Hardware Software Overview

c. A lookup table modifies the intensity values of images (for range and contrast effects). This operation requires only a delay of several pixels.

d. A warp card transforms the image in the Y axis on a line-by-line basis. The starting point (offset) and magnification factors shift and compress or expand the pixels of each line. This operation delays the flow of pixels by one line.

e. A second identical high-speed read/write X and Y axis memory card accepts and stores the transformed Y data for an odd and even field to form a frame. After the Y axis field is loaded in the Y axis, the X axis data is read out by line, and even and odd fields. This buffer operation requires one video frame.

f. A second warp card identical to Y processes X axis data by shifts and expands or compresses lines. Again, this operation delays the image by approximately one video line.

Figure 13 shows a possible hardware implementation of a processing channel.

CGSI System Configuration

CGSI uses a modular set of building blocks which may be configured to meet specific training and simulation requirements. A system may be configured for a wide FOV visual color display or a narrow FOV sensor display. In addition, CGSI may be added to existing CGI systems as a product improvement to improve realism and fidelity.

CGSI STATUS

The feasibility of CGSI in non-real time has been demonstrated using a video tape showing a nap-of-the-earth helicopter flight. The CGSI demonstration video tape shown at the conference was generated in non-real time. All the algorithms, edges, perspective, dust, smoke, shadows, etc., were tested in non-real time. A real-time CGSI system has been designed for NAVTRAEQUIPCEN/PM TRADE under the contract ***"Extend CGSI Concept."***

Because of the high potential payoff from the development of this hybrid approach, the Navy and the Army have current plans aimed at demonstrating feasibility of this CGSI technology in real-time. CGSI pipeline processors will be interfaced to NAVTRAEQUIPCEN's Visual Technology Research Simulator (VTRS) facility for evaluating CGSI concepts and for demonstrating combined multisensor displays. Figure 14 demonstrates the high fidelity and realism of CGSI.

ABOUT THE AUTHORS

Mr. Carl P. Graf has degrees in Psychology, Math, and Engineering. His 20 years of experience at Honeywell in the man-machine interface area include: Apollo and LBM manual controllers, eye tracking, eye switching, passive and active camouflage, maintenance trainers, image processing, multisensor imagery and displays, dual resolution displays, and the generation of high fidelity imagery.

Ms. Dorothy M. Baldwin obtained her M.A. in Physics from Kent State University in 1968 and her B.A. in Physics from Hartwick College in 1965. Her 13 years of professional experience have been in government and academia. Her 5 years at Naval Training Equipment Center includes work on the 360 laser scan display system, the helmet mounted display system, and the annular projection system. Her current assignments include: Principal Investigator on the Multi-Spectral Image Simulation Project and Advanced Sensor Simulation Project.

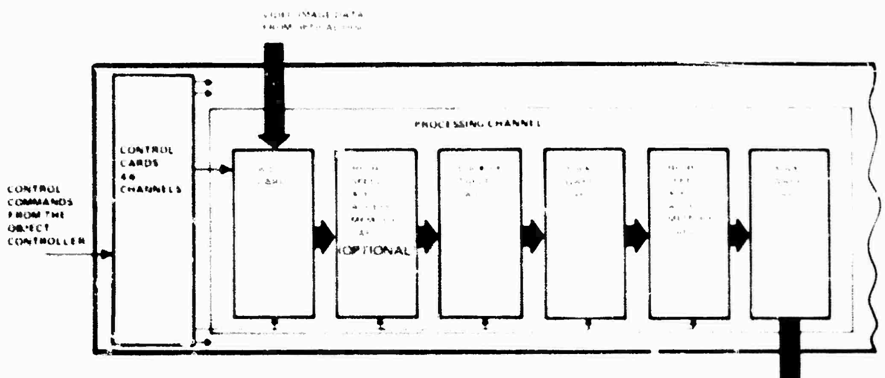

Figure 13. Processing Channel

Figure 11. CGSI